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ANALYSIS OF SEISMIC DATA FOR THE RIO BLANCO EXPLOSION

D. H. von Seggern

Teledyne Geotech

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ABSTRACT

Seismic analysis of RIO BLANCO, an underground nuclear explosion for gas stimulation, was performed using LRSM, LPE, and array recordings. Although a multiple detonation, RIO BLANCO was similar to other western U. S. shots and especially RULISON, another gas-stimulation explosion 55 km away. Magnitude-yield relations, shear generation, and spectral content of RIO BLANCO were not untypical for underground explosions. A source function which includes pP and P_{spall} was inferred from the seismic data. An accurate location was obtained for RIO BLANCO using travel-time anomalies for RULISON.

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INTRODUCTION

RIO BLANCO was the third of a series of gas-stimulation nuclear explosions in the PLOWSHARE program. Basic site information on this shot is given in Table I. The feature of interest was the multiple nature of the shot--actually three simultaneous and closely spaced detonations. A previous gas stimulation shot, RULISON, was located 55.9 km to the southeast of the RIO BLANCO site. RULISON was not a multiple shot; therefore, comparisons of its signals with those of RIO BLANCO should help to elucidate what, if any, effects the multiple detonation had on seismic signals.

In this report we examine several seismic aspects of the RIO BLANCO shot, including location, magnitude, source function, and shear-wave generation. Comparisons are made with RULISON especially and with nuclear explosions and earthquakes in the western United States in general. The report on RULISON by Lambert and Ahner (1972) is the basic reference for this report; it will often simply be referred to as "the RULISON report" hereafter.

TABLE I

RIO BLANCO Detonation Information

Date:	17 May 1973
Time:	16:00:00.1
Location:	39°47' 34.8"N, 108°21'59.6"W
Surface Elevation:	6630 ft. (2010 m)
Shot Depths:	5840, 6230, and 6690 ft. (1780, 1900, and 2040 m) (aligned vertically)
Uphole Time:	.527 sec.
Yield:	30 kt for each of three detonations
Medium:	Sandstone (Fort Union and Mesa Verde formations)

DATA

The data source used for this report on RIO BLANCO comprised ten portable LRSM (Long Range Seismic Measurements) stations, the three on-line VELA arrays (LASA, ALPA, and NORSAR), the ten Long-Period Experimental (LPE) stations, and the limited TFO array. Magnetic tape data, either analog or digital, were available at the SDAC for these sites, with the exception of a few LPE sites.

The ten LRSM stations were deployed especially for RIO BLANCO, but usable long-period and short-period recordings were not available from all sites. The LRSM recordings of RIO BLANCO are displayed in Appendix I. Horizontal components were aligned radially and transversely with the shot location.

The arrays were all operational for RIO BLANCO, but short-period seismometers at LASA and TFO, both within 8° of the shot, were clipped and thus unusable except for travel-time determination. Long-period signals were seen at LASA and ALPA but not at NORSAR. The array recordings of RIO BLANCO are displayed in Appendix II.

Data for RIO BLANCO from the ten LPE sites operating at that time was disappointing. Only long-period recordings are available from these stations, and of the ten, just three stations detected surface waves (ALQ, OGD, and CHG). Displays of the RIO BLANCO recordings from the three stations are contained in Appendix III. Appendix IV is a map showing the shot point location and the station locations at which data was recorded for RIO BLANCO.

The seismic data as read from the displayed recordings from RIO BLANCO is presented in Table II. Ground motions have been calculated using appropriate instrument response curves. Body-wave magnitudes have been calculated using both Evernden's (1967) and Gutenberg and Richter's (1956) correction terms; for regional distances Evernden's formulas for 7.9 km/sec and 8.5 km/sec refractors were used as indicated, and for teleseismic distances Gutenberg and Richter's formula was applied as indicated by "G-R". In all cases the same formulas as were applied to RULISON stations (Lambert and Ahner, 1972) were used for corresponding RIO BLANCO stations. The RULISON report discusses the choice of the appropriate formula. Surface-wave magnitudes have been calculated using von Seggern's (1970) distance-correction term for regional ($\Delta < 15°$) distances or Gutenberg's (1945) distance-correction term for teleseismic ($\Delta > 15°$) distances. Again, in all cases the same formulas were applied to RIO BLANCO sites as were applied to those identical RULISON sites. The body-wave formulas are:

m_e (7.9) = 1.21 (log A/T + 3.04 log r) - 7.55 (Evernden, 1967)

m_e (8.5) = log A/T + 2 log r - 3.27 (Evernden, 1967)

m_b (G-R) = log A/T + B (Gutenberg and Richter, 1956)

where A is maximum <u>zero-to-peak</u> amplitude in millimicrons, T is period, r is distance in kilometers, and B is tabulated by Gutenberg and Richter (1956).

TABLE II

Principal Phases for RIO BLANCO

Code	Station	Distance km.	Distance deg.	Instrument	Phase	Travel min.	Time sec.	Period sec.	A/T mμ/sec	Magnitude m_b	Magnitude M_s	Comments
ALQ	Albuquerque, New Mexico	545	4.90	LPN	LR	03	20.0	21.0	661.0		4.36	LPZ overdriven
TFO	Tonto Forest, Arizona	647	5.82	SPZ	P	01	32.3					all SPZ clipped
				LPZ	LR	03	[illegible]	17.0	216.0		4.26	ZILL instrument
LAO	LASA, Montana	807	7.25	SPZ	P	01	45.2					all SPZ clipped
				LPZ	LR	04	10.0	18.0	230.0		4.40	LP beam
LC-NM	Las Cruces, New Mexico	816	[illegible]	SPZ	P	01	55.5	0.5	13.3	4.52		7.9 refractor-emergent
				LPT	LQ	04	30.0	20.0	26.0			
				LPZ	LR	04	50.0	14.0	323.0		4.55	
BP-CL	Bishop, California	932	8.38	SPZ	P	[illegible]	7.3	0.35	25.4	5.05		7.9 refractor
				LPZ	LR							LP seis. malfunctioning
[illegible]NB	Crete, Nebraska	985	8.86	SPZ	P	02	11.4	0.35	247.	5.13		8.5 refractor-emergent
				LPZ	LR	05	40.0	14.0	265.		4.56	
SJ-TX	San Jose, Texas	1624	14.60	SPZ	P	03	34.6	0.7	14.0	4.30		8.5 refractor-emergent
				LPT	LQ	08	50.0	19.0	14.[illegible]			
				LPZ	LR	09	50.0	15.0	142.0		4.54	
RK-ON	Red Lake, Ontario	1692	15.22	SPZ	P	03	29.6	0.7	48.3	4.90		Gutenberg-Richter formula
				LPT	LQ							possible LQ, but noisy
				LPZ	LR							spurious transients
WQ-IL	Watseka, Illinois	1765	15.88	SPZ	P							signal masked by local
					LR	10	0	14.0	162.0		4.32	noise source
PG2BC	Prince George, British Columbia	1921	17.27	SPZ	P	04	02.2	0.5	70.5	4.75		Gutenberg-Richter
				LPT	LQ	09	40.0	14.0	59.6			formula
				LPZ	LR	10	50.0	12.0	120.0		4.25	
BE-FL	Belleview, Fla.	2681	24.11	SPZ	P							bad magnetic tape
				LPZ	LR	15	20.0	15.0	28.8		3.88	recording
OGD	Ogdensburg, New Jersey	2848	25.61	LPZ	LR	15	30.0	20.0	27.8		3.90	
WH2YK	Whitehorse, Yukon	2973	26.74	SPZ	P	05	41.[illegible]	0.7	15.7	4.67		Gutenberg-Richter formula
				LPZ	LR							masked by Japan earth-quake
HN-ME	Houlton, Maine	3332	29.97	SPZ	P							short-period seis.
				LPT	LQ	16	10.0	[illegible]	52.2			are noisy
				LPZ	LR	18	10.0	16.0	103.0		4.58	
ALPA	ALPA, Alaska	3789	34.07	LPT	LQ	19	10.0	23.0	10.7			horizontal rotated beam
				LPZ	LR	21	20.0	21.0	[illegible]		3.92	vertical beam
KIP	Kipapa, Hawaii	5092	45.79	LPZ								no signals
NAO	NORSAR, Norway	7570	68.08	SPZ	P	10	57.6	1.0	36.1	5.56		vertical beam
				LPZ	LR							no visible LR phase
CHG	Chiang, Mai, Thailand	12928	116.27	LPZ	LR	75	40.0	19.0	2.83		3.87	

The surface-wave formulas are:

$$M_s^* = \log A/T + 1.16 \log \Delta + 0.74 \quad \Delta < 15°$$
(von Seggern, 1970)

$$M_s = \log A/T + 1.66 \log \Delta - 0.18 \quad \Delta > 15°$$
(Gutenberg, 1945)

Where A now is measured in millimicrons peak to peak on the vertical component. Note that a constant -0.18 appears in the last formula; this makes our M_s that much lower than would be commonly calculated by NOAA and others. This constant appears when making a strict conversion to vertical LR measurement from horizontal LR measurement as originally proposed by Gutenberg (see Lambert and Ahner, 1972).

RESULTS

Location

Using the nearby RULISON explosions, we have the opportunity with RIO BLANCO to test the relative travel-time location method in a new area. The method is that of Chiburis and Ahner (1970). Due to the several factors, mostly poor first arrivals, it was judged that only four stations common to RULISON and RIO BLANCO had reliable enough data for accurate P arrival times. This is the minimum number required for a least-squares solution when depth is constrained as was done here. These times are given in Table III; the RULISON times were repicked by the author and do not necessarily correspond to those of the RULISON report; this was done to insure utmost compatibility between RULISON and RIO BLANCO signal start points.

RIO BLANCO lies 55.9 km northwest of RULISON. Using the arrival times for RIO BLANCO and the anomalies for RULISON shown in Table III, the location computed for RIO BLANCO was 2.04 km nearly due east of ground zero. The final standard deviation of travel-time errors was .403 seconds, and the 95% confidence ellipse based on the F-statistic for epicenter location enclosed 458 km^2. This magnitude of error is remarkably small considering the distance between the two events and the number of stations used. The location precision is slightly better than that typically achieved at NTS (Chiburis and Ahner, 1970), but this may be fortuitous since the sets of arrival times used here are still considered to be

TABLE III

Arrival times used for location of RIO BLANCO with RULISON anomalies

Station	RIO BLANCO Arrival Time	RIO BLANCO Residual*	RULISON Arrival Time	RULISON Residual*
BP-CL	16:02:07.3	4.2	21:02:11.1	4.8
RK-ON	16:03:29.6	-3.1	21:03:31.8	-2.3
PG2BC	16:04:02.2	3.3	21:04:08.3	3.2
TFO	16:01:32.4	3.1	21:01:29.5	3.1

*Relative to 1967 Herrin tables

somewhat uncertain. However, this case shows that the minimum four stations may be sufficient to make a good location when travel-time anomalies are employed.

Magnitude

Taking all the magnitudes, both regional and teleseismic, in Table II, RIO BLANCO has an average M_s = 4.26 and an average m_b = 4.86 with 95% confidence limits of $\pm$.16 and $\pm$.28, respectively. These station magnitudes are listed in Table IV along with RULISON magnitudes wherever available. The RULISON report gives M_s = 3.84 $\pm$.15 and m_b = 4.59 $\pm$.24 for that shot using all available data (26 Rayleigh wave observations and 27 P wave observations). A more accurate comparison of the two shots' magnitudes would use only common stations as seen in Table IV. With just the nine common stations for M_s, the surface wave magnitude difference between RIO BLANCO and RULISON is 0.30; and with the eight common stations for m_b, the body wave magnitude difference is 0.25. The yield of RULISON is reported to be approximately 40 kt (Springer and Kinnaman, 1971), and that of RIO BLANCO is approximately 90 kt (Project Directors' Completion Report D+30 Days Project RIO BLANCO, Atomic Energy Commission). In this yield range, far-field seismic amplitude is both predicted (von Seggern and Blandford, 1972) and observed (Springer and Hannon, 1973; Evernden, 1970) to be approximately proportional to yield for both body waves and surface waves. Thus the amplitudes

TABLE IV

Comparison of RULISON and RIO BLANCO Magnitudes

Station	M_s RIO BLANCO	RULISON	m_b RIO BLANCO	RULISON
BE-FL	3.88	3.46	-	-
BP-CL	-	4.03	5.05	4.58
CR2NB	4.56	4.27	5.13	5.02
HN-ME	4.58	4.22	-	4.78
LC-NM	4.55	4.11	4.52	4.17
PG2BC	4.25	3.89	4.75	4.43
RK-on	-	3.48	4.90	4.89
SJ-TX	4.54	4.31	4.30	4.06
WH2YK	-	-	4.67	-
WQ-IL	4.32	3.99	-	4.64
TFO	4.26	4.12	-	4.56
LASA	4.40	4.25	-	5.06
NORSAR	-	-	5.56	-
ALPA	3.92	-	-	-
ALQ	4.36	-	-	-
OGD	3.90	-	-	-
CHG	3.87	-	-	-

for RIO BLANCO should be 2¼ times those of RULISON, a difference of 0.35 on the magnitude scale. Our observed differences of 0.30 and 0.25 are in good agreement with this prediction, and the lack of complete agreement can most likely be attributed to coupling and near-source effects, provided the stated yields are accurate. We conclude that RIO BLANCO behaved much as a single concentrated source would insofar as magnitudes are concerned. Considering the proximity of the three detonations as given in Table I, this is not an unexpected result for far-field observations.

The actual time delays between the RIO BLANCO shots can be estimated as follows. The uphole time was .527 sec (Sisemore and Toman, 1973); this gives an uphole velocity of 11,100 ft/sec (3.38 km/sec) from the topmost detonation. Using this velocity at shot level (though a higher velocity undoubtedly applies there) the time delays of downward rays at the source are .041 sec and .076 sec for the middle and topmost detonation relative to the bottommost one. Rays at any angle to the vertical will be delayed less, by a factor of $\cos(i_0)$ where i_0 is the angle of incidence. For regional distances this cosine factor should be 0.7 or less. Figure 1 shows examples of the effect on m_b by summing signals with these time delays. The primary pulse is a synthetic one based on the ω^{-2} source function discussed by von Seggern and Blandford (1972). It was created for a 30 kt source, a value T/Q (travel-time over quality factor) of .54, and a LRSM short-period instrument.

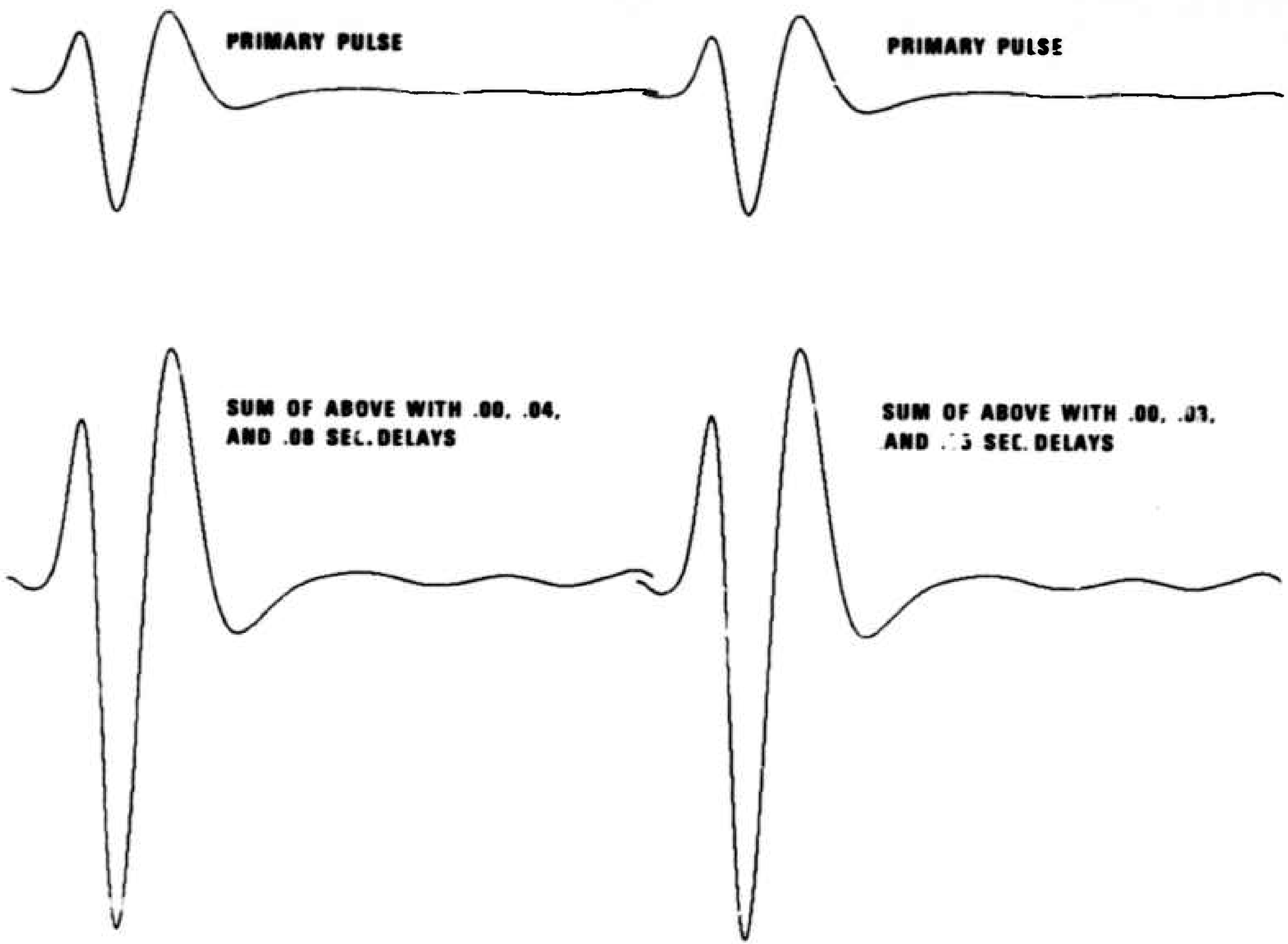

Figure 1. Synthesis of three-shot RIO-BLANCO signals (bottom) using expected delays of a single shot (top) for teleseismic (left) and regional (right) distances.

The two larger pulses are those resulting when maximum delays are used as stated above (appropriate for core phases) and when 0.7 times these maximum delays are used (appropriate for regional distances) in summing up the three 30 kt shots to simulate RIO BLANCO short period signals. (The simulated signals had 100 samples per second, and so the delays were rounded to the nearest .01 second.) The amplitudes of the summed signals with delays are within 3% of the value that would result if the primary pulse were merely multiplied by a factor of three to represent a single 90 kt detonation. Also, no perceptible increase in period occurs. Thus the magnitude decrease of the three 30 kt shots emplaced as for RIO BLANCO relative to a single 90 kt detonation should be less than .02 m_b unit. However, this assumes no inelastic effects at the source, whereas the RIO BLANCO shot configuration probably led to attenuation of downgoing waves from detonations above by the cavities and inelastically deformed surroundings of detonations below. Our conclusions cannot be precise, but these arguments suggest that the three RIO BLANCO detonations should not produce quite as strong a signal as the combined total of the yields would predict. Our magnitude comparisons of RIO BLANCO with RULISON, considering the error involved, does not confirm this expectation, but neither does it refute this expectation.

The RULISON report presented M_s-m_b for many earthquakes and explosions in the United States, and Figure 2 shows the RIO BLANCO point (using all

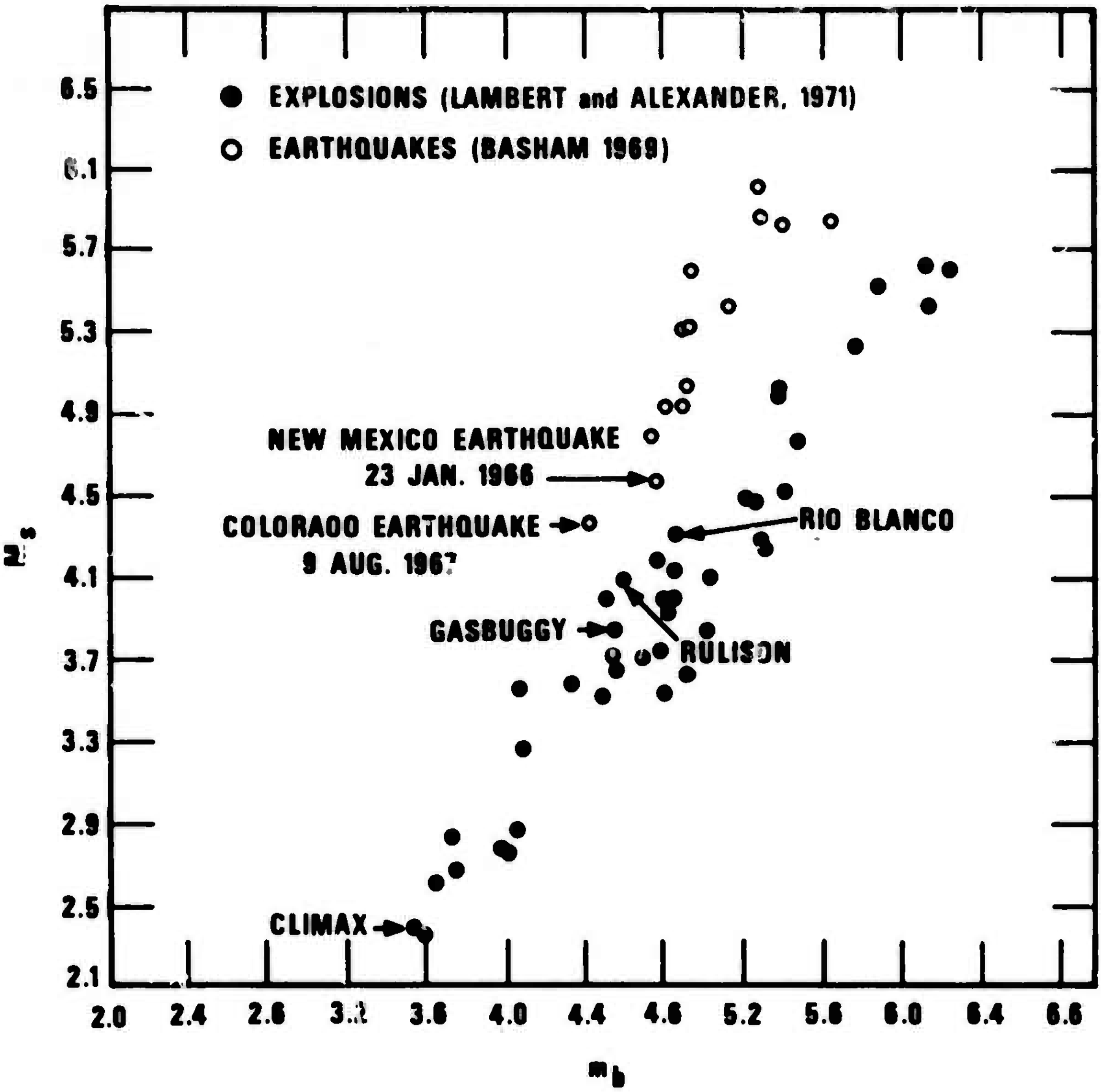

Figure 2. M_s versus m_b for RIO BLANCO compared to western United States explosions and earthquakes.

available data in Table II) on that plot. The RULISON point here represents all available data in that report. In both cases, and also for the other points in this plot, the appropriate m_b and M_s formulas have been used for regional distances in the western United States. Although it lies toward the upper extreme of explosions, RIO BLANCO is apparently well separated from western United States earthquakes.

Source Function

We have already pointed out the similarity of the three RIO BLANCO detonations to a single detonation insofar as magnitudes are concerned. The time delays for seismic far-field signals are so small that indications of a multiple source should be non-existent in the seismic recordings. Therefore, we do not expect to find multiple-shot information by applying to P wave signals such techniques as spike filtering, homomorphic filtering, or cepstral analysis. However, the contribution of the source function from pP and spalling signals can be studied with these techniques, and such results for RIO BLANCO should be of interest because of its abnormal firing depth compared to most NTS shots.

In the RULISON report, cepstral analysis was applied with nonuniform and indefinite results for the LRSM stations used; however, processing of LASA signals indicated a pP at approximately the expected time and also a later signal with the same polarity as P which may be interpreted as the spalling P wave. Unfortunately,

LASA recordings were clipped for the RIO BLANCO P wave. Cepstral analysis for the six LRSM stations with adequate S/N ratios are shown in Figure 3. This processing is described by Cohen (1969). Basically one examines the spectrum for nulls appearing at frequencies appropriate for pP or P_{spall} interference and the cepstrum for a peak at the approximate time delays. For RIO BLANCO, Sisemore and Toman (1973) show the uphole time to be .53 sec; and so pP should be delayed by roughly 1.1 sec. Their accelerograph data also show the P_{spall} signal to be delayed by .29 sec at ground zero relative to pP, and so P_{spall} should arrive roughly 1.4 sec after P on RIO BLANCO recordings. Using $f_N = n/\tau$ (n = 0, 1, 2,...) for pP null frequencies, one should expect spectral nulls at 0.9, 1.8, 2.7, etc. cps for pP; and using $f_N = n/\tau$ (n = 1/2, 3/2, 5/2, etc) for P_{spall} null frequencies, one should expect nulls at 0.4, 1.1, 1.8, 2.5, etc. cps. These nulls appear for many of the stations in Figure 3; but the sum spectrum, which should smooth out individual path and station irregularities in the spectra, does not clearly contain any of these nulls. All of the individual stations except LC-NM show a spectral null in the 0.8-0.9 cps range, roughly correct for the pP interference, but the slight variability of the null frequency among stations apparently leads to cancellation of this on the sum spectrum. Also a null frequency at roughly 1.1-1.2, indicative of P_{spall}, can be seen on some stations; but again this is smoothed out in the sum spectra.

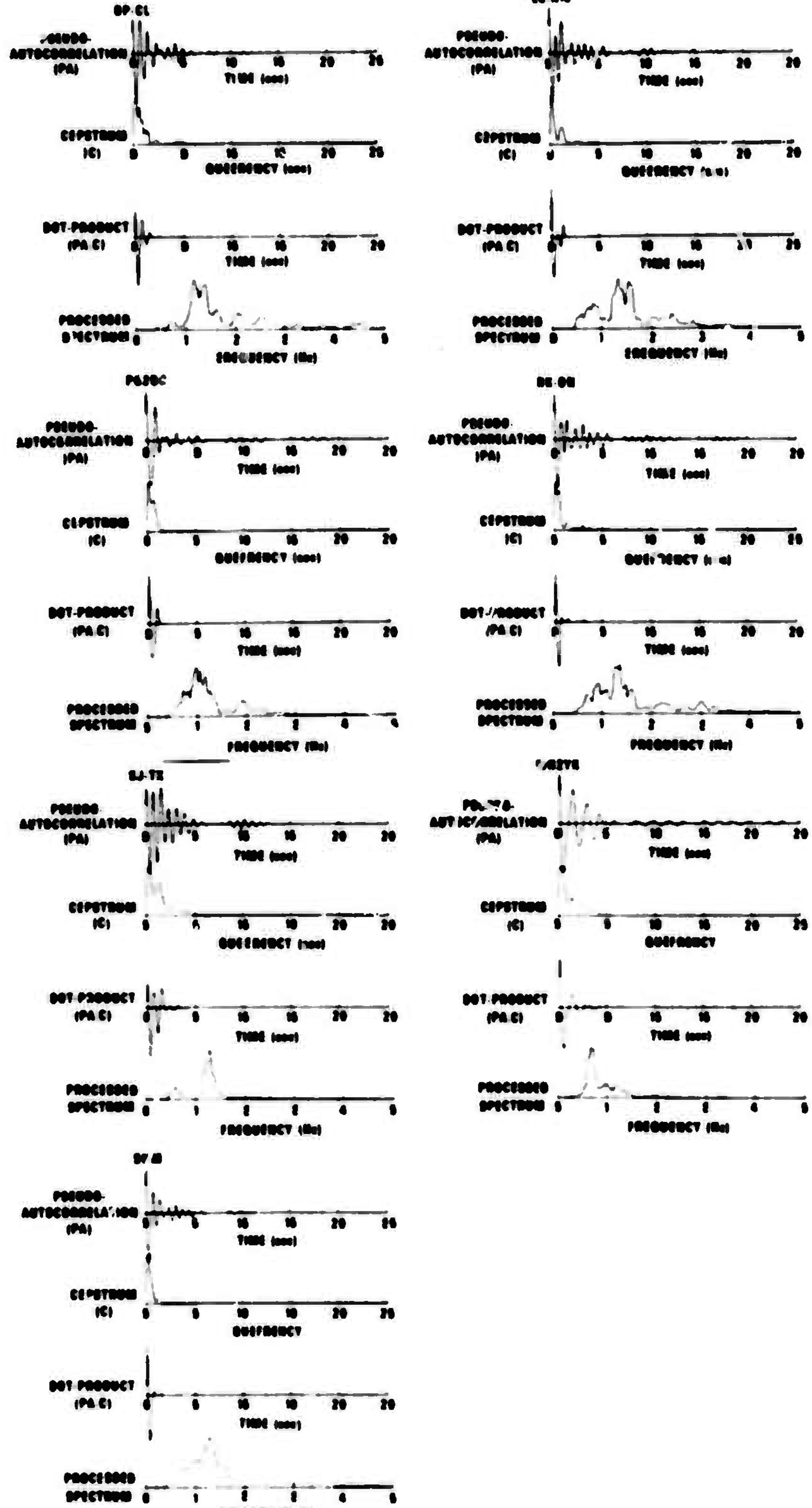

Figure 3. Cepstrum analysis for RIO BLANCO.

Another technique available is homomorphic filtering. This is explained in detail by Schaeffer (1969), and it has been employed with success on Amchitka Island test site signals by Bakun and Johnson (1973). Because the technique works only on minimum-phase signals, we are limited to data that is beyond regional distances where secondary arrivals can make the signal very non-minimum phase. The only P signals from our data base that were judged to be amenable to this processing were at NORSAR and WH2YK, and a time-dependent weighting factor (Schaeffer, 1969) was necessary to make them even approximately minimum phase. The sampling rate for these signals was 20/sec, and the first 5 sec of data was extended to twice its length with zeroes before processing. Figure 4 shows the homomorphic filtering results for the two stations. The weighting factors were $.96^{20t}$ and $.98^{20t}$ for NORSAR and WH2YK respectively. (In these figures the complex cepstrum is wrapped around; that is, the last half of the complex cepstrum trace represents negative time and should be placed to the left of the start of the trace. Significant amplitudes at $t<0$ indicate that the signal analyzed is not completely minimum phase.) The complex cepstrum was windowed with a box-car function from -0.8 sec to 0.8 sec to recover the primary pulse and from 0.8 sec onward to recover the echo train, which hopefully would show spikes for pP and P_{spall} with appropriate signs and delays relative to the primary signal. In both cases in Figure 4, a

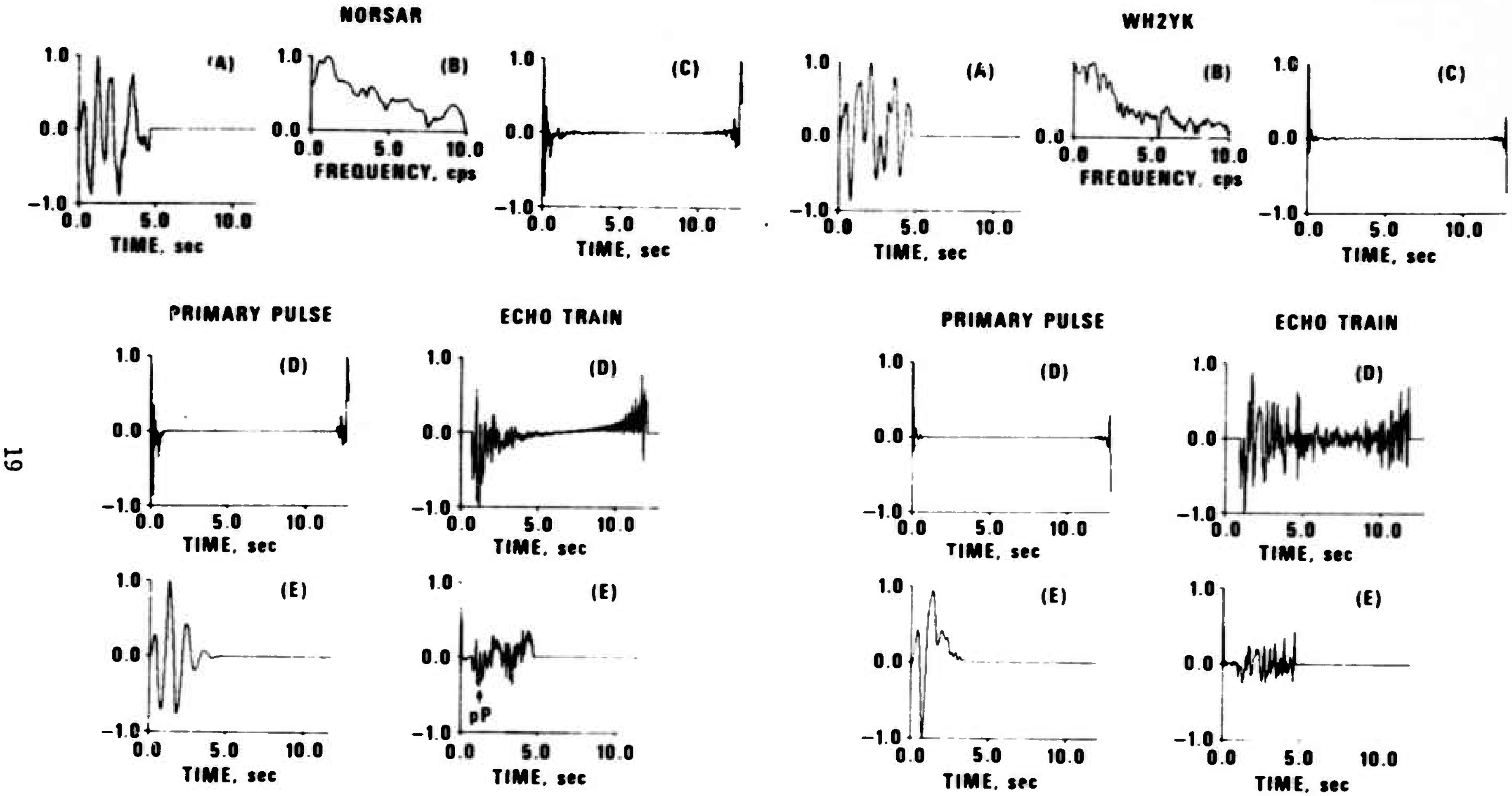

Figure 4. Homomorphic filtering for RIO BLANCO where: a) signal, b) log-amplitude spectrum, c) complex cepstrum, d) windowed complex cepstrum, e) recovered signal or echo train.

negative excursion near 1.2 sec is in apparent rough agreement with the 1.1 sec expected pP delay. No conclusions are possible for a P_{spall} though.

A requirement for good results with homomorphic filtering is that the primary signal and its echos have the same relative shape. But the WH2YK and NORSAR signals appear to have lower frequencies beginning about 2 or 3 sec after onset of the primary P. It may well be that the spall signal is enriched in lower frequencies relative to the explosion P signal; the larger temporal and spatial scale of spalling relative to a concentrated detonation would seem to require this (Viecelli, 1973). If this is the case, one would not expect to necessarily see the spall signal revealed by suppressing the short-time part of the complex cepstrum to recover the echo train. In fact, the change of frequency content with time on the analyzed record will certainly distort the results for the primary pulse shape and pP delay time too.

We also employed the inverse filtering technique described by Douglas et al. (1972) to NORSAR and WH2YK. Again, as with homomorphic filtering, this technique requires well-recorded teleseismic signals. The inverse filter is that filter which reduces to a spike the convolution of the appropriate instrument response with an attenuation operator given by Futterman (1962). The Futterman operator has negligible effect on the phase spectrum of seismic signals at teleseismic distances even. T/Q values of .93 for WH2YK and .74 for NORSAR were used (since the NORSAR signal was beamformed and high

frequencies were thus attenuated somewhat, the value of .74 for T/Q is undoubtedly higher than would be needed for a single instrument there). The inverse filtering results are displayed in Figure 5. The second trace from the bottom is the raw output when the inverse filter is run over the data trace, and the bottom trace is merely the result of using a low-pass filter on the raw output. The bottom trace should be an estimate of the source displacement-time function, since instrument and path responses have been removed by the inverse filter. In both cases we see the negative excursion indicative of pP at approximately 1.2 sec. Another equally strong pulse occurs positively at approximately 2.0 sec. According to data at the site itself, P_{spall} should only be delayed by about 1.4 sec; so either this is not the P_{spall} signal or that signal somehow had a delay approaching 2.0 sec. The only other explanation for these strong positive pulses at WH2YK and NORSAR other than spall signals would be secondary arrivals along paths separate from, but nearly identical to, that of the primary P path. This is a problem which our limited data is unable to resolve.

Study of the RIO BLANCO source function has not yielded precise results. We are more confident of pP evidence than P_{spall} evidence since several approaches have indicated a pP signal at approximately 1.1-1.2 sec as expected. The best evidence for P_{spall} is in the time traces themselves, where a lengthening of the dominant period, roughly 2 sec after P, could reflect

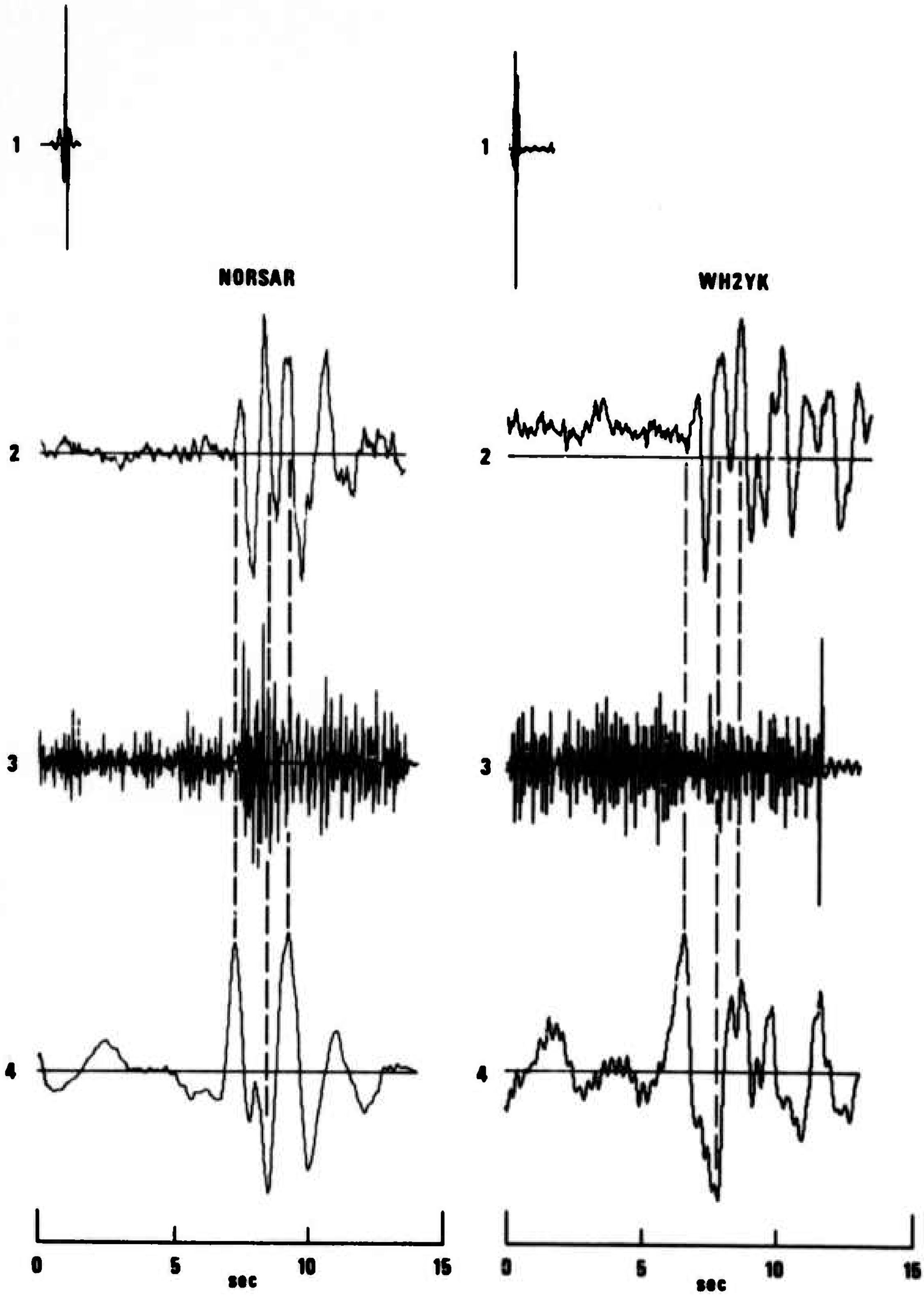

Figure 5. Inverse filtering for RIO BLANCO where: 1) inverse filter, 2) signal, 3) convolution of above, 4) low-pass filter output of (3), an estimate of source displacement function.

a source contribution which is more extensive in time or space than the initial P. In addition, amplitudes equal to initial P occurring 3 to 4 sec after P are most easily explained by a strong spalling phenomenon.

Shear Generation

No direct S waves were identified on the RIO BLANCO recordings analyzed for this report. This accords with the fact that no S waves are listed in the data of the RULISON report. For RIO BLANCO, five stations in Table II have Love-wave amplitudes reported. The average LQ/LR ratio from these five stations is 0.30. From the RULISON report, where nearly twice as many stations were listed with LQ, one obtains a LQ/LR ratio of 0.53. Thus the two shots were within roughly a factor of two in their relative excitation of Love waves. From all the available LRSM and VELA observatory data for NTS and Amchitka Island explosions, von Seggern (1972) reports an average LQ/LR ratio of roughly 0.6. This indicates that the Colorado shots were apparently somewhat less effective generators of Love waves than the established test sites, although there is insufficient data to declare this with any great confidence.

Spectra

In Figure 6 we show the P-wave spectra of RIO BLANCO as recorded at seven of the ten LRSM stations (no signals were recorded at HN-ME or BE-FL, and WQ-IL had a very noisy recording). These spectra are of the

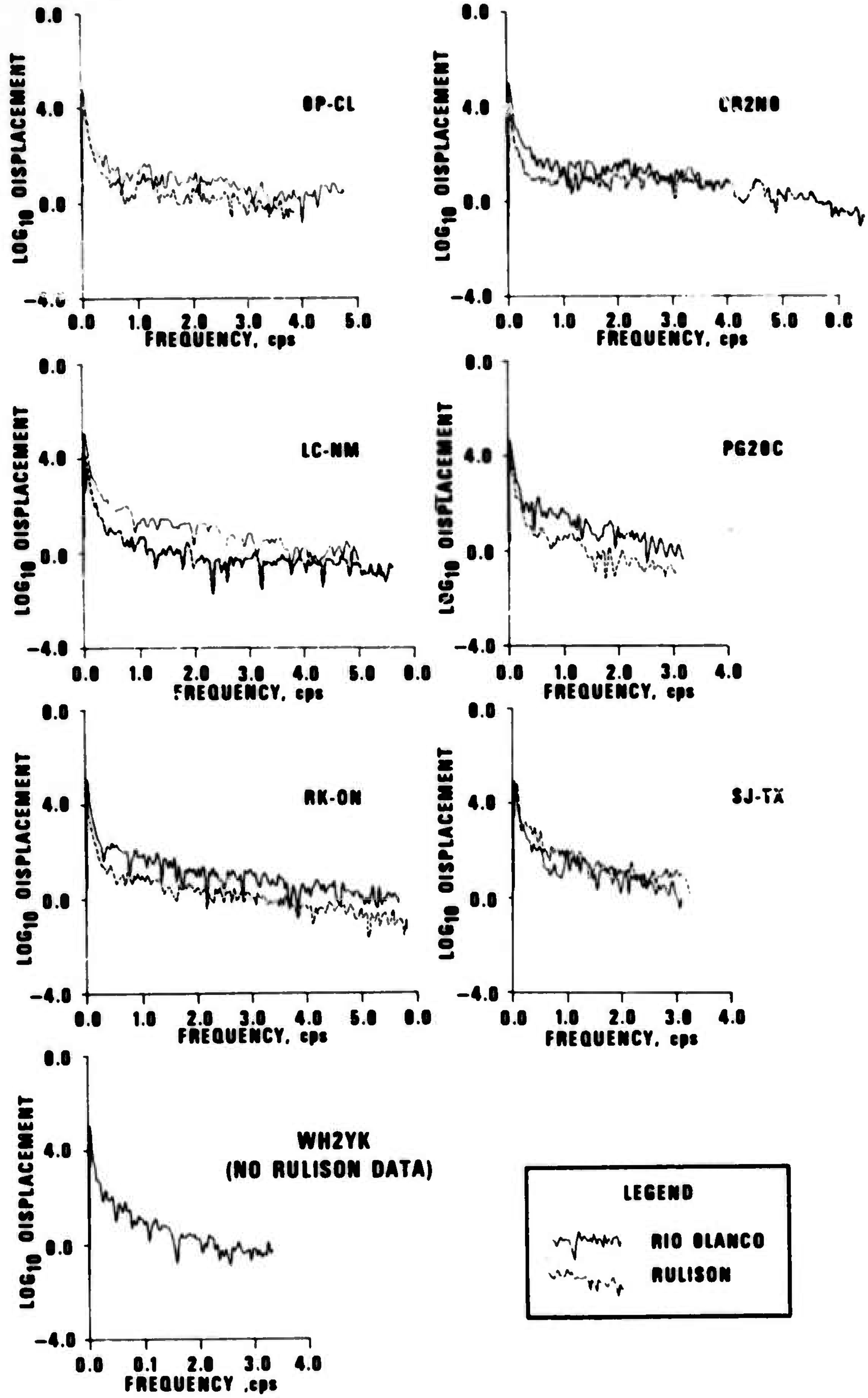

Figure 6. P-wave spectra for RIO BLANCO and RULISON.

first 25 sec of signal after the P onset, sampled at 20 points per second. Noise spectra of the 25 sec preceding the P were used to approximately determine the high frequency at which S/N ratio fell to 1.0, and the signal spectra were accordingly truncated at this point. This was not done at low frequencies since the S/N ratio seemed to be above 1.0 to nearly the lowest frequencies sampled. These spectra have been corrected for instrument response and are in units of ground displacement. The corresponding RULISON spectra were computed for comparison in each case, except for WH2YK where a recording was not made for that shot. The vertical scales of the two shots have been arbitrarily adjusted for best comparison of spectral shape. The spectra of the two shots are very similar at all stations except LC-NM, where low S/N ratios prevailed. The short-period spectra thus confirm the similarity of RULISON and RIO BLANCO as seismic sources.

Long-period signals from RULISON and RIO BLANCO were near overlays in all cases, and a spectral comparison was therefore not made of these signals. Spectral ratios for LR calculated in the RULISON report should apply to RIO BLANCO within a few per cent. That report showed that RULISON LR spectral content was as expected for explosions.

SUMMARY

Data from only a few North American sites and the NORSAR array were sufficient to locate and roughly characterize the RIO BLANCO event. In spite of the multiplicity of the detonation, RIO BLANCO signals did not differ in any apparent manner from ordinary explosions, with RULISON as the main comparative measure. Through homomorphic filtering, inverse filtering, and cepstral analysis, we were able to see the pP reflection and possibly the spall impact. No direct shear waves were identified for RIO BLANCO and Love wave generation was less than that of typical NTS shots. Spectral content of P signals for RIO BLANCO was similar to RULISON, and LR signals were visually similar at stations common to both events.

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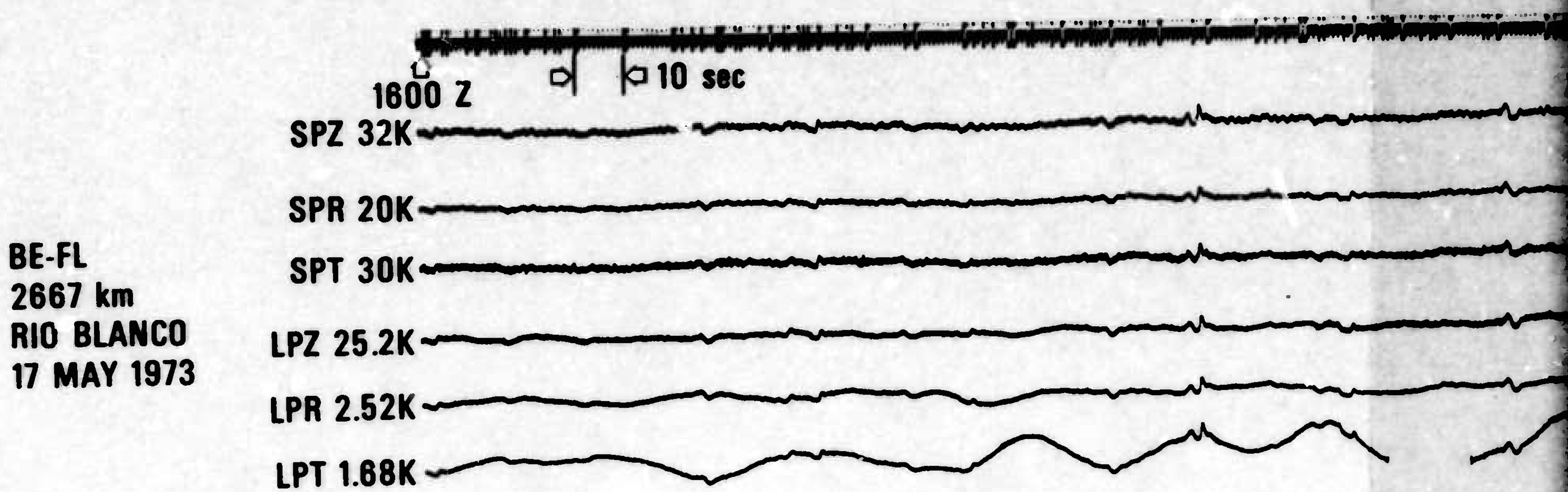
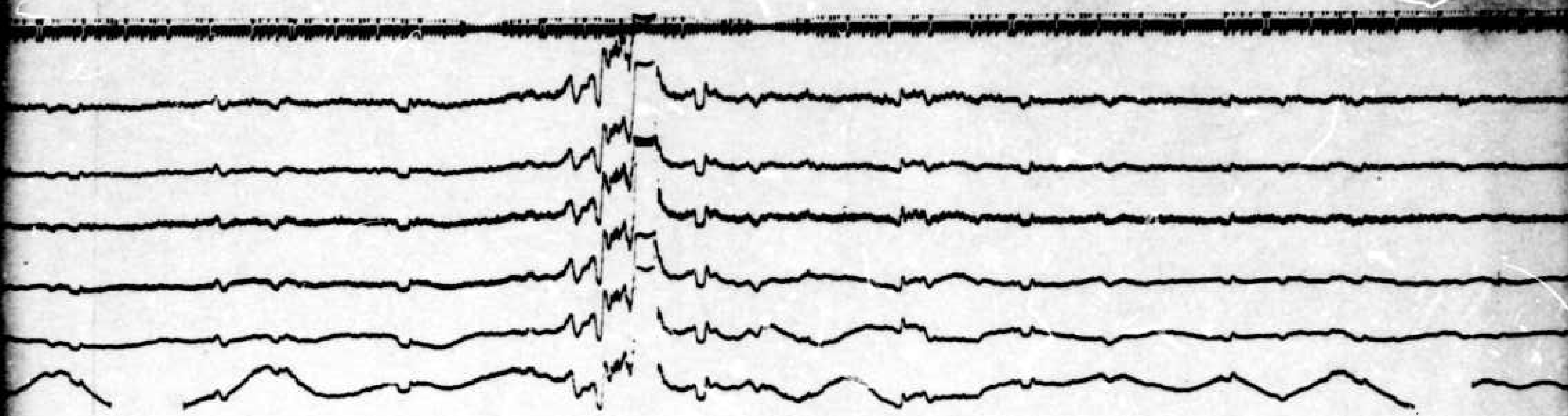
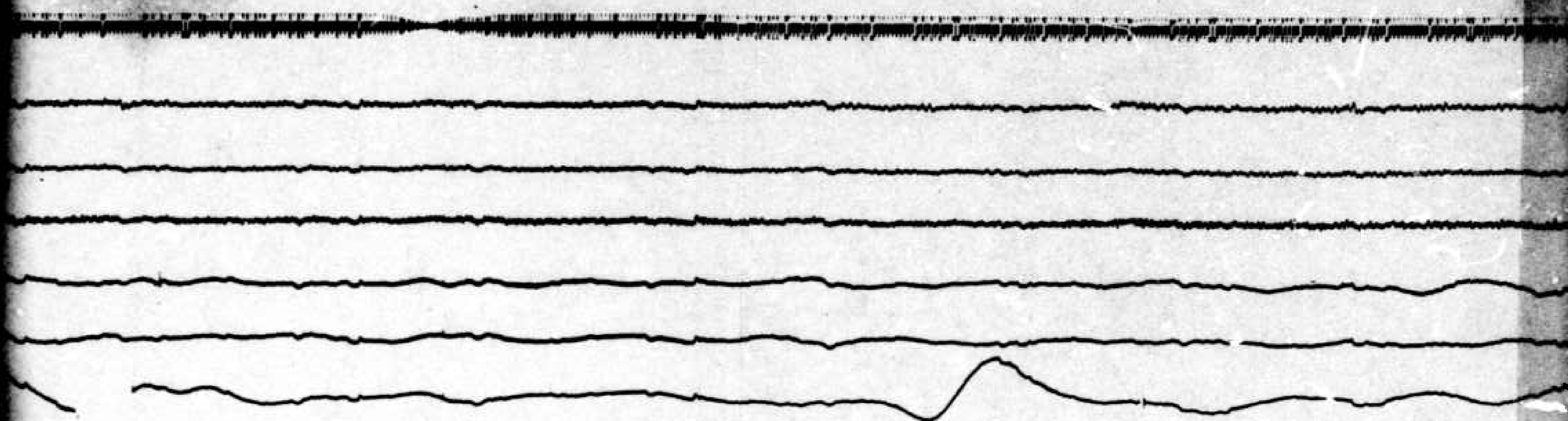
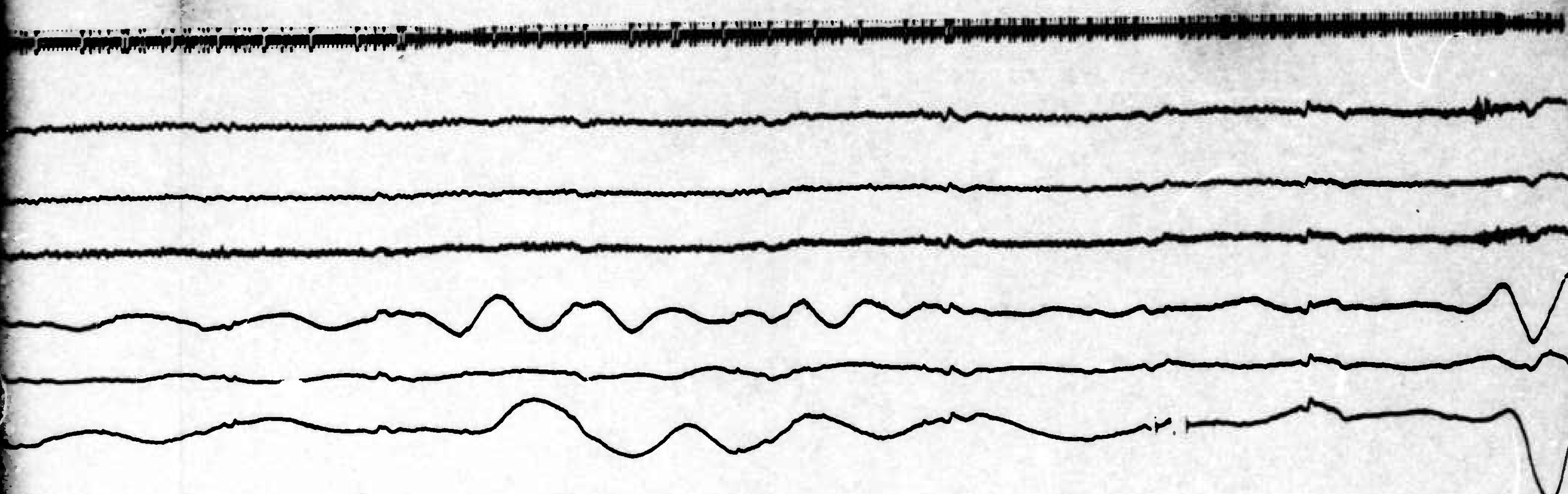
APPENDIX I

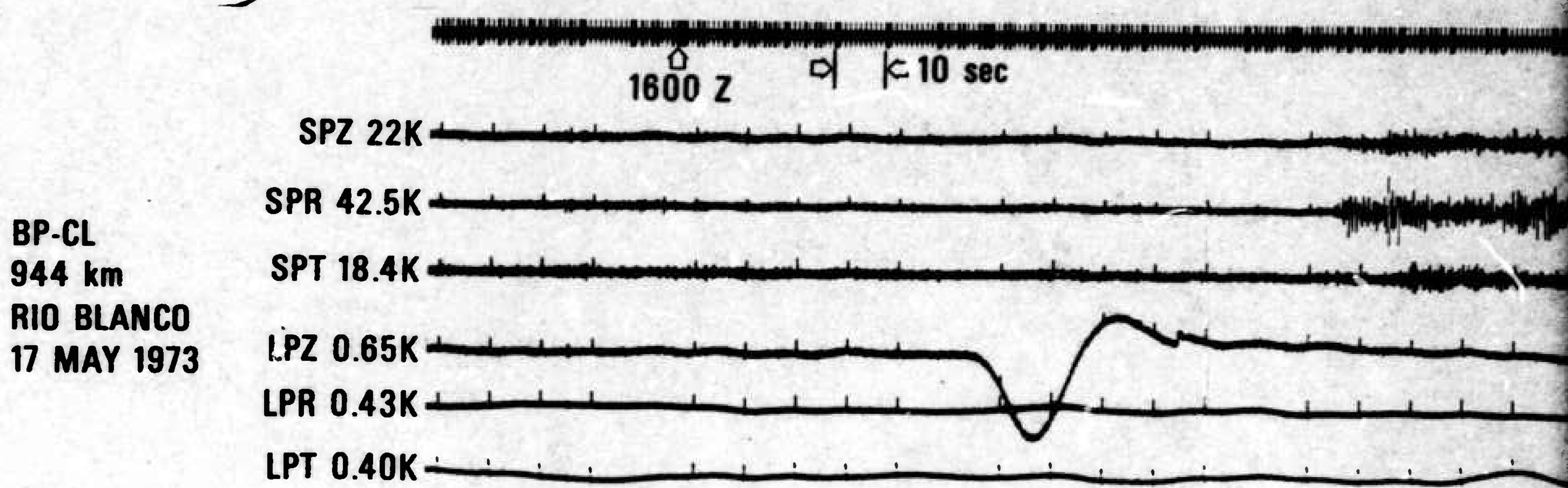
LRSM DATA

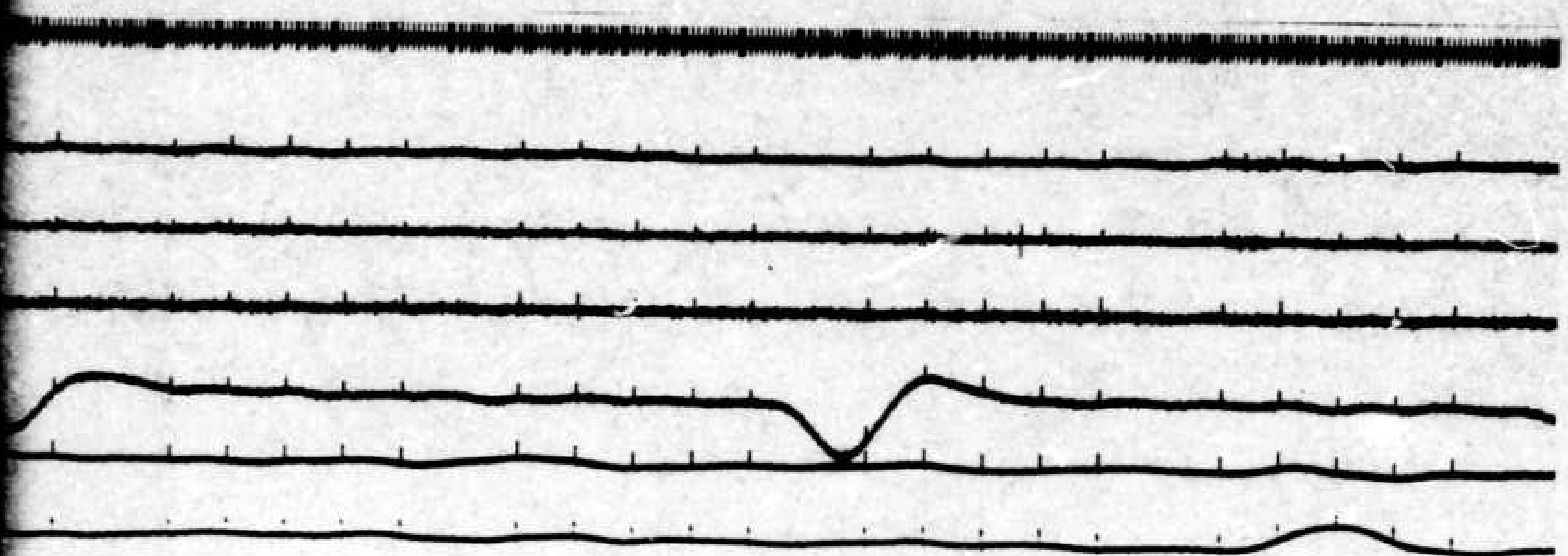

BE-FL
2667 km
RIO BLANCO
17 MAY 1973
1600 Z
10 sec
SPZ 32K
SPR 20K
SPT 30K
LPZ 25.2K
LPR 2.52K
LPT 1.68K

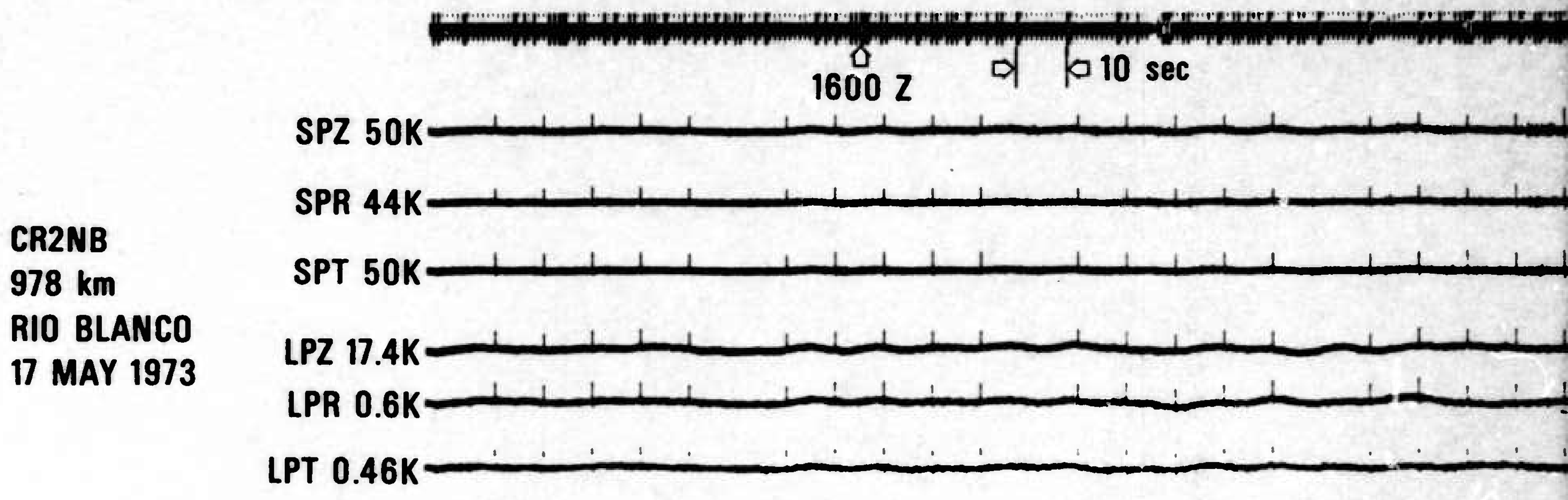


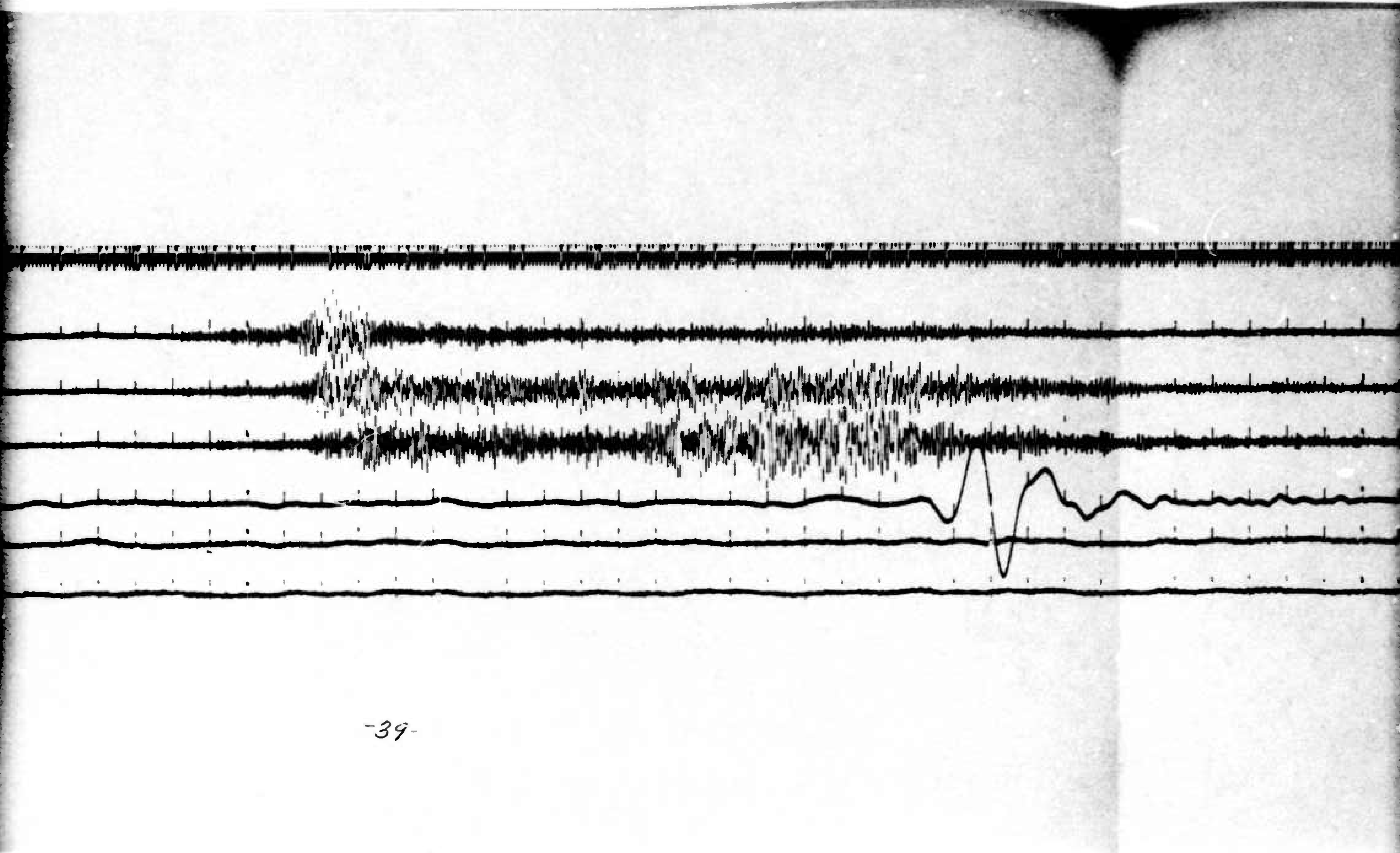


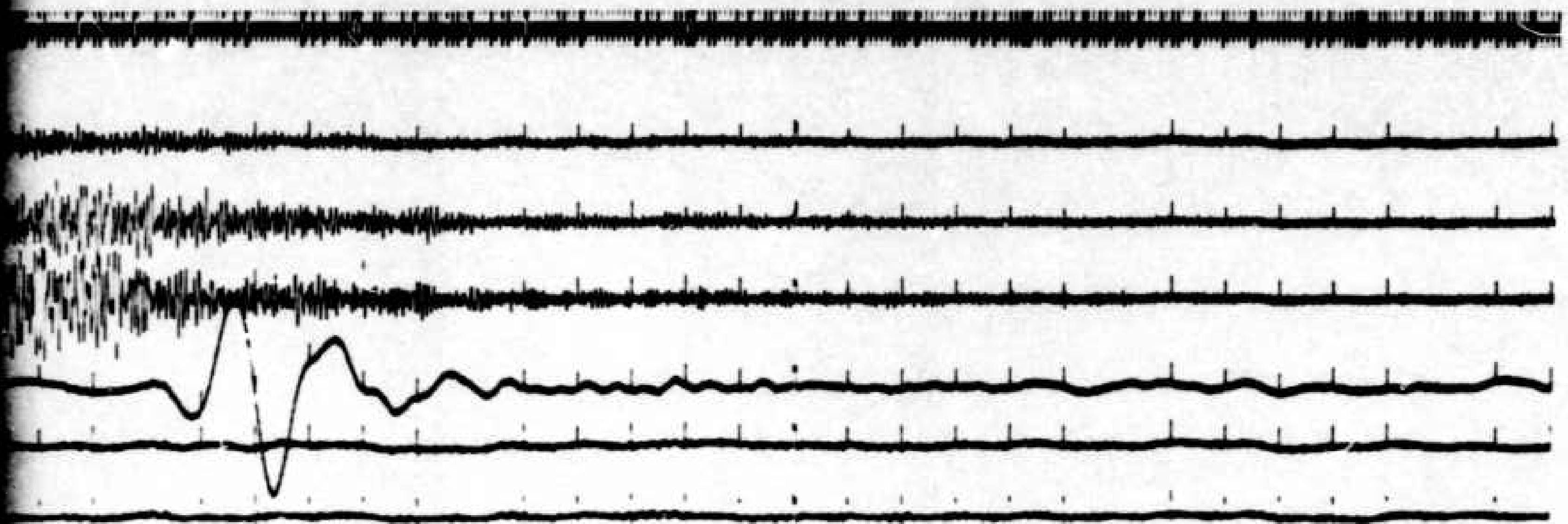


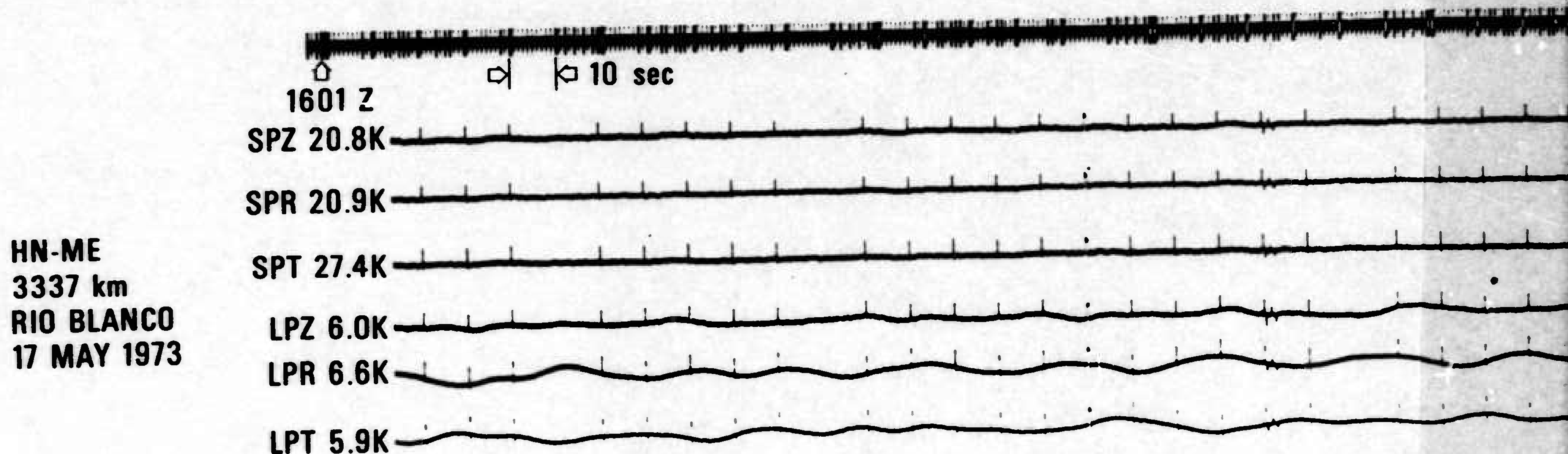

BP-CL
944 km
RIO BLANCO
17 MAY 1973
1600 Z
10 sec
SPZ 22K
SPR 42.5K
SPT 18.4K
LPZ 0.65K
LPR 0.43K
LPT 0.40K

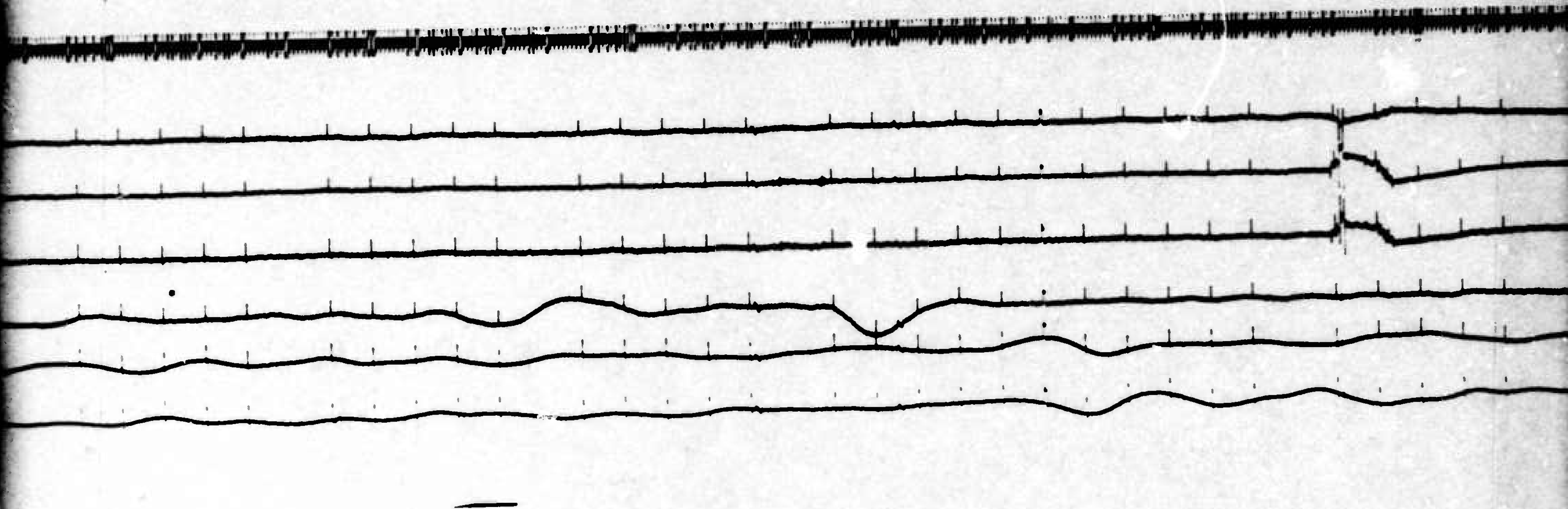


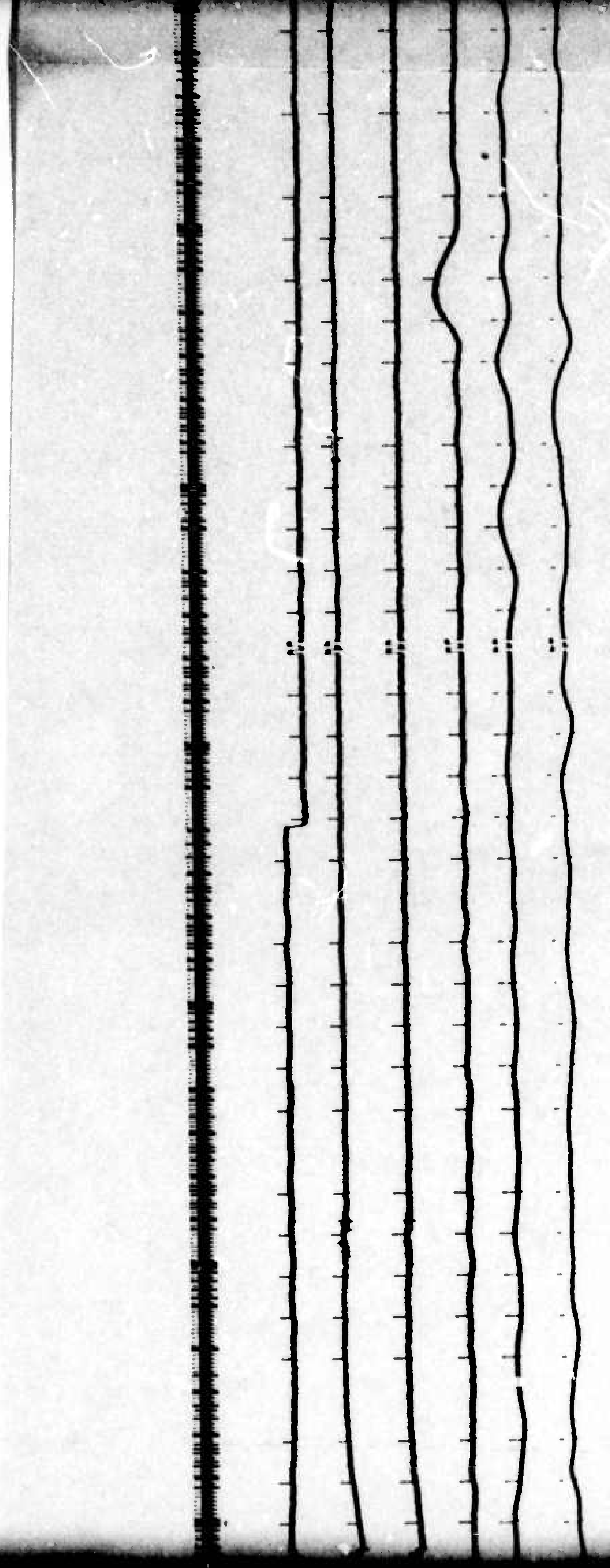

CR2NB
978 km
RIO BLANCO
17 MAY 1973
1600 Z
10 sec
SPZ 50K
SPR 44K
SPT 50K
LPZ 17.4K
LPR 0.6K
LPT 0.46K

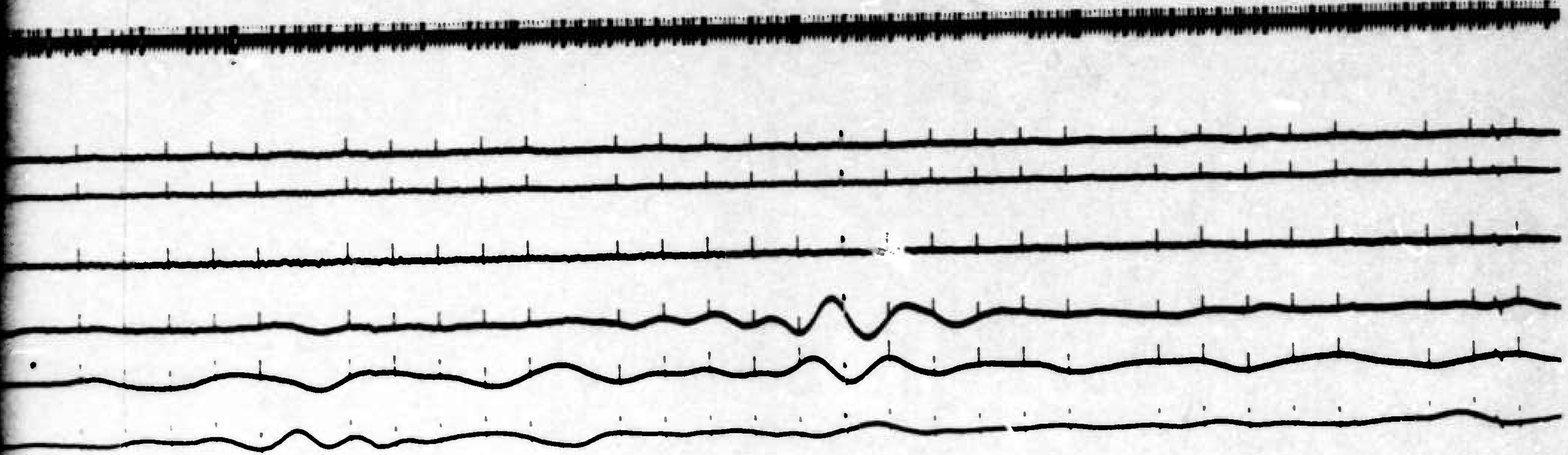




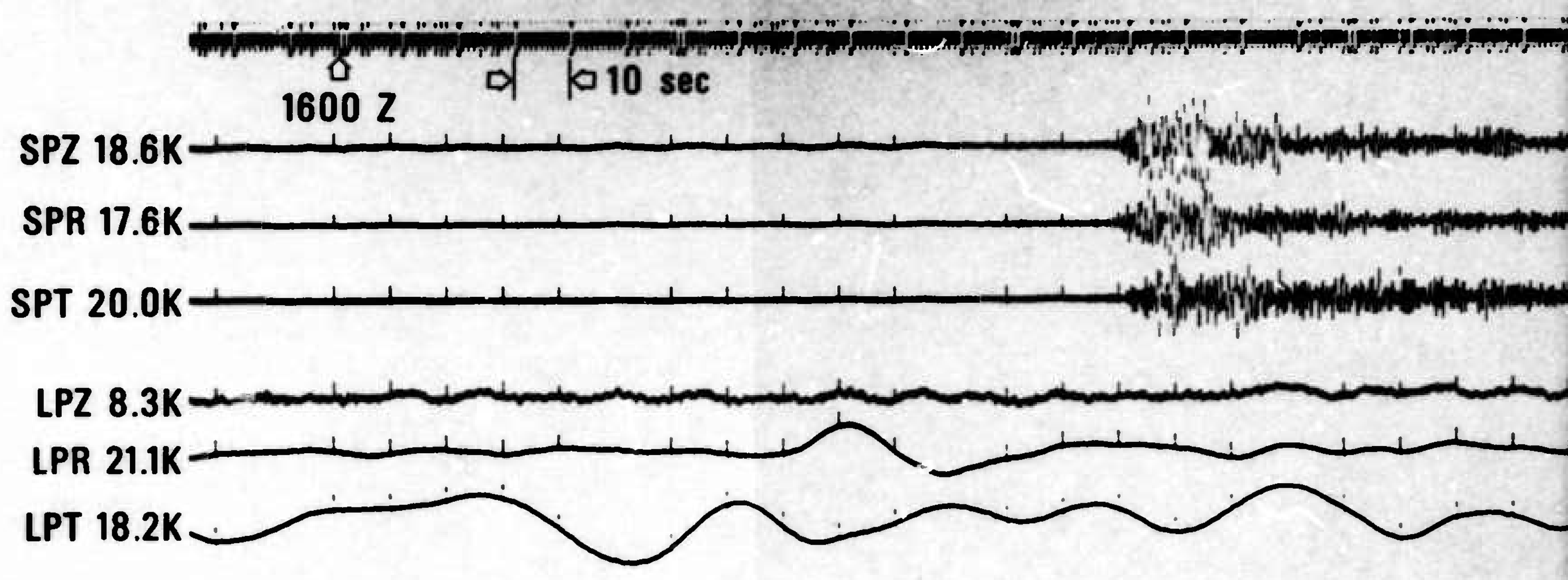

HN-ME
3337 km
RIO BLANCO
17 MAY 1973
10 sec
1601 Z
SPZ 20.8K
SPR 20.9K
SPT 27.4K
LPZ 6.0K
LPR 6.6K
LPT 5.9K

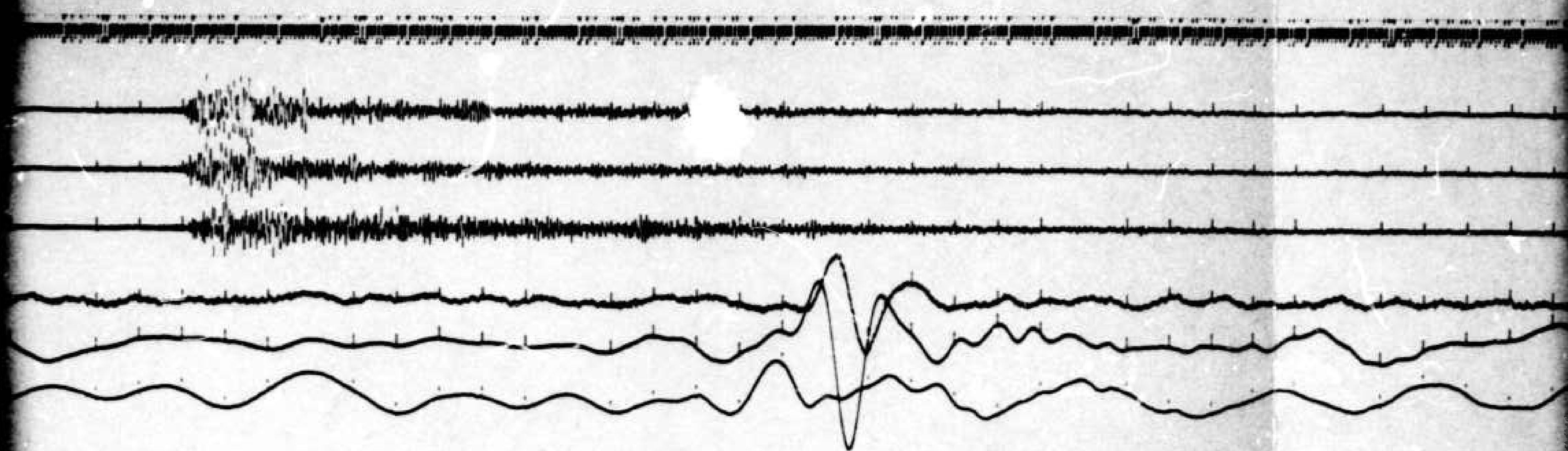


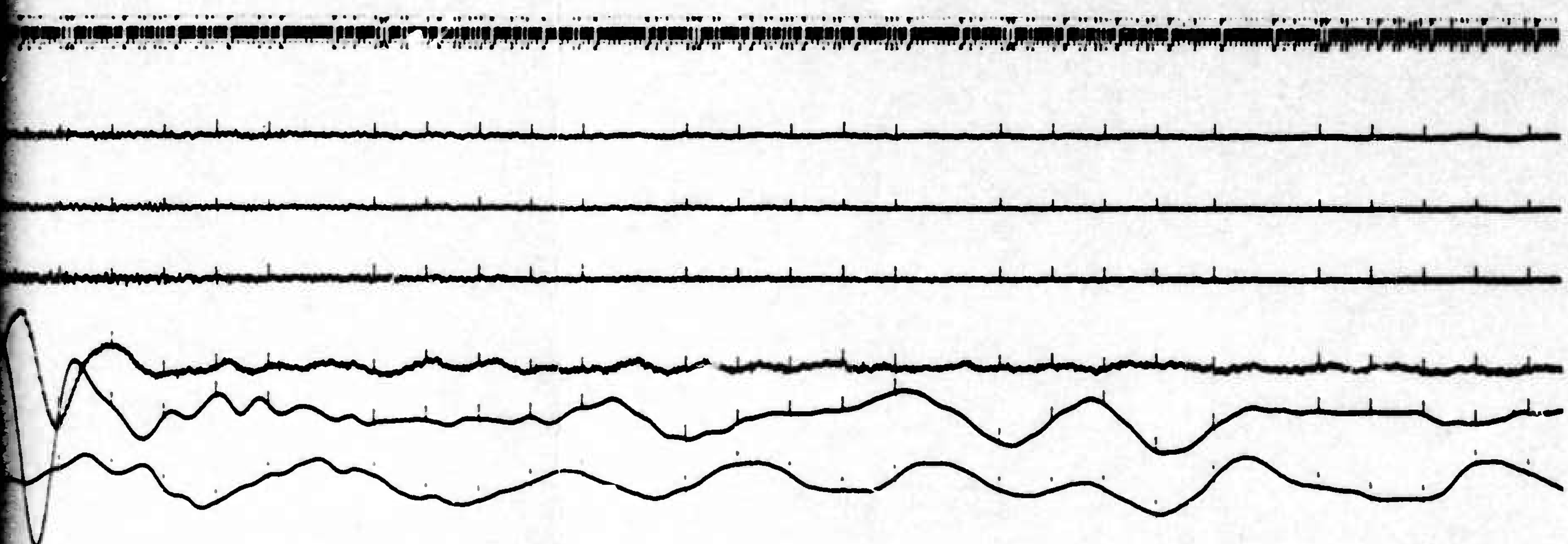


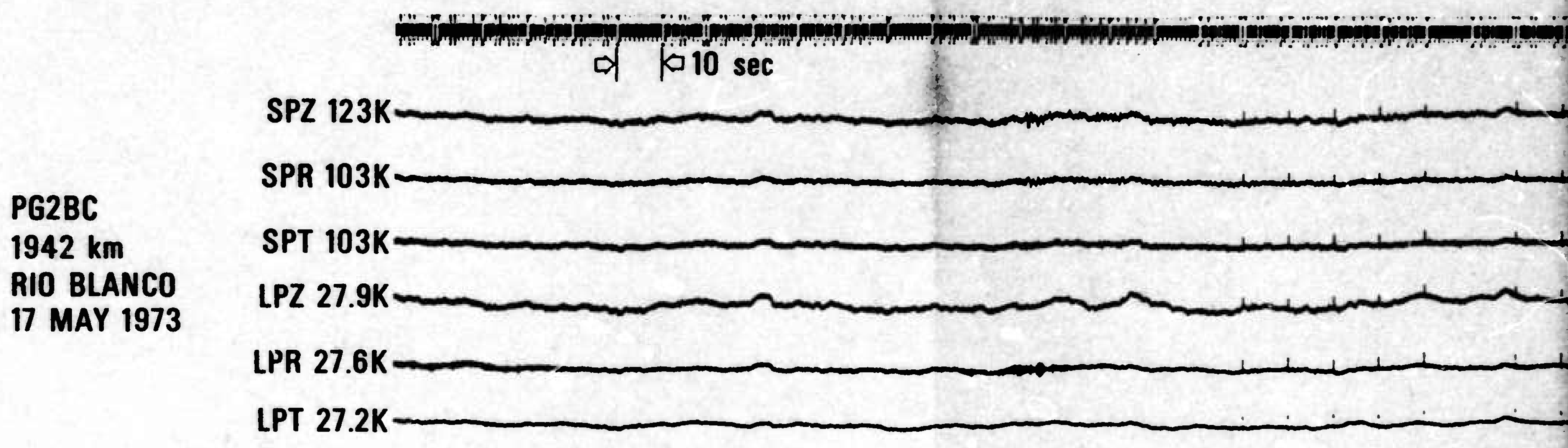


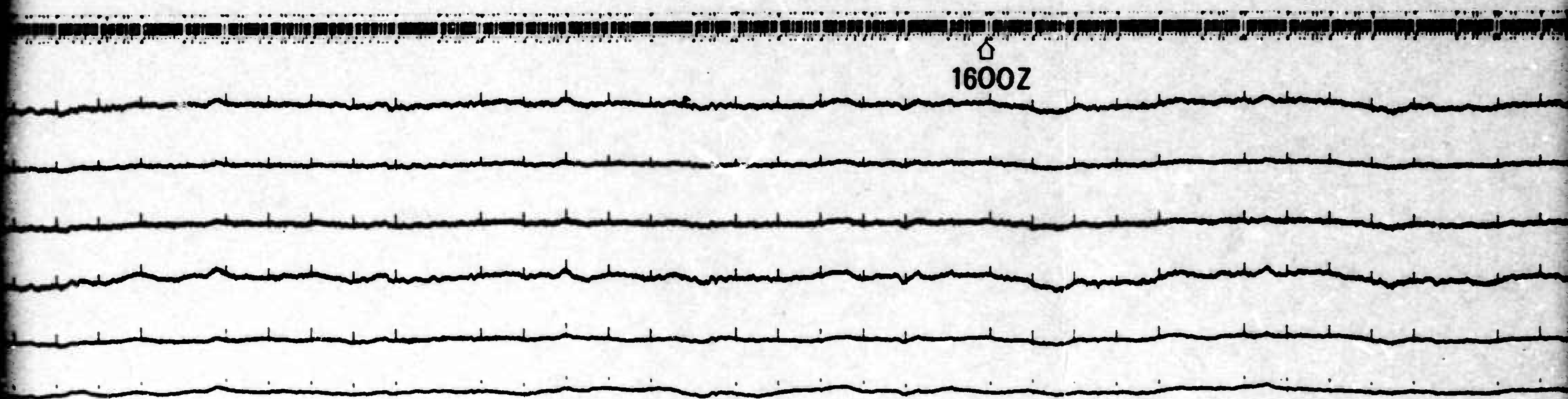
LC-NM
798 km
RIO BLANCO
17 MAY 1973

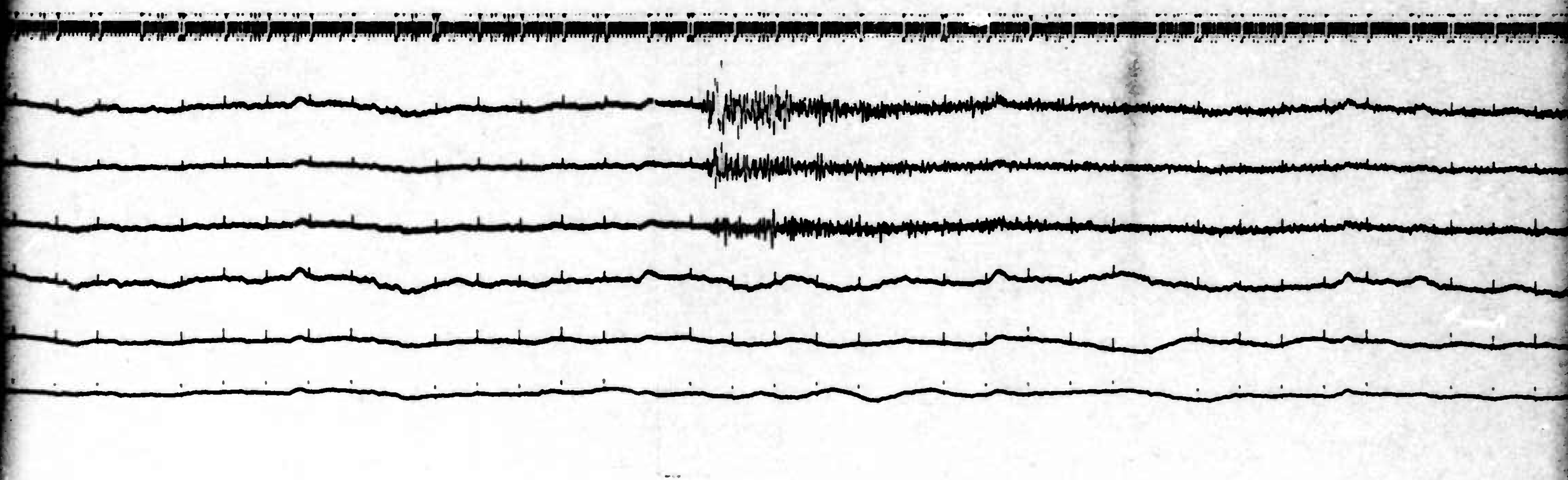


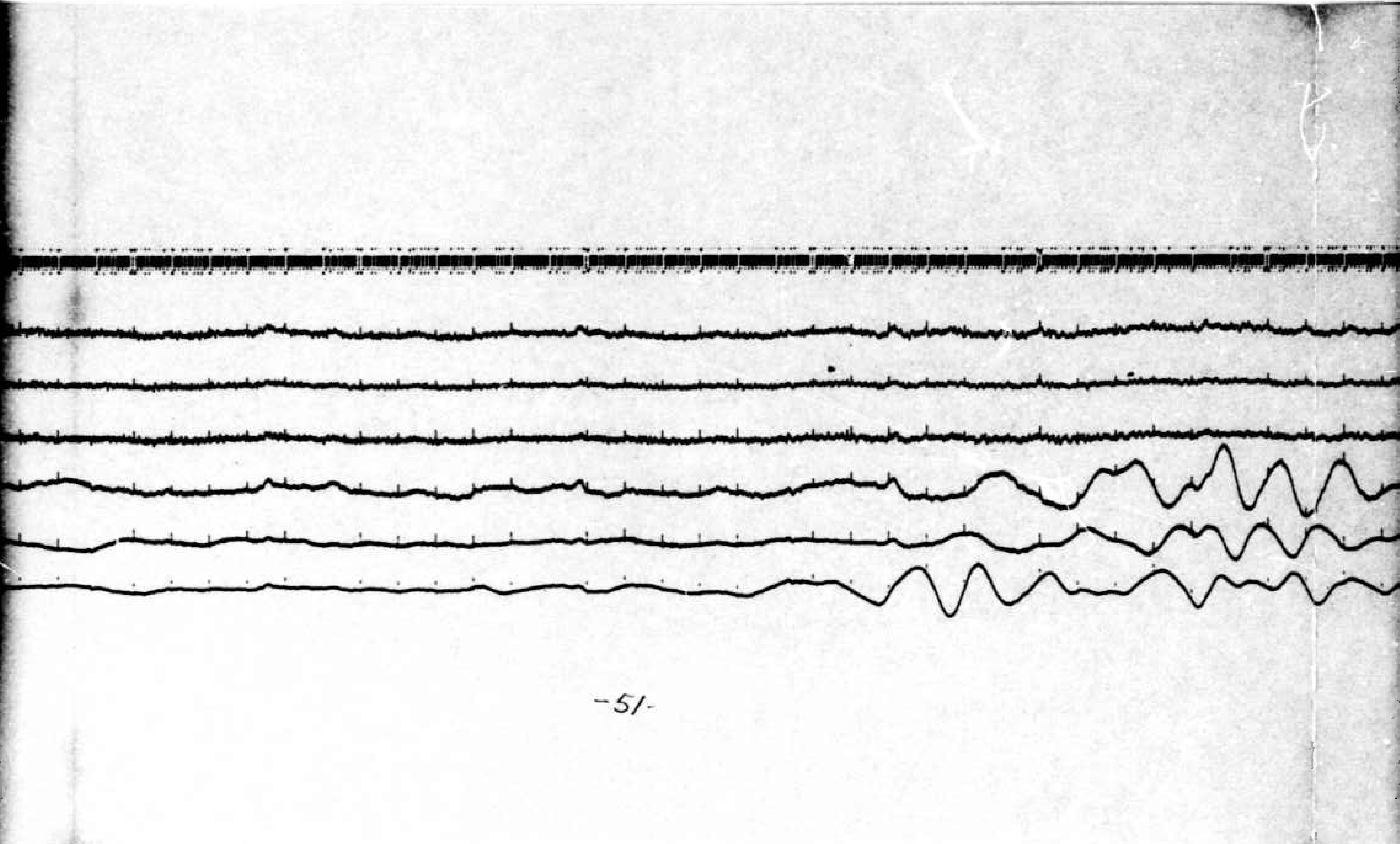


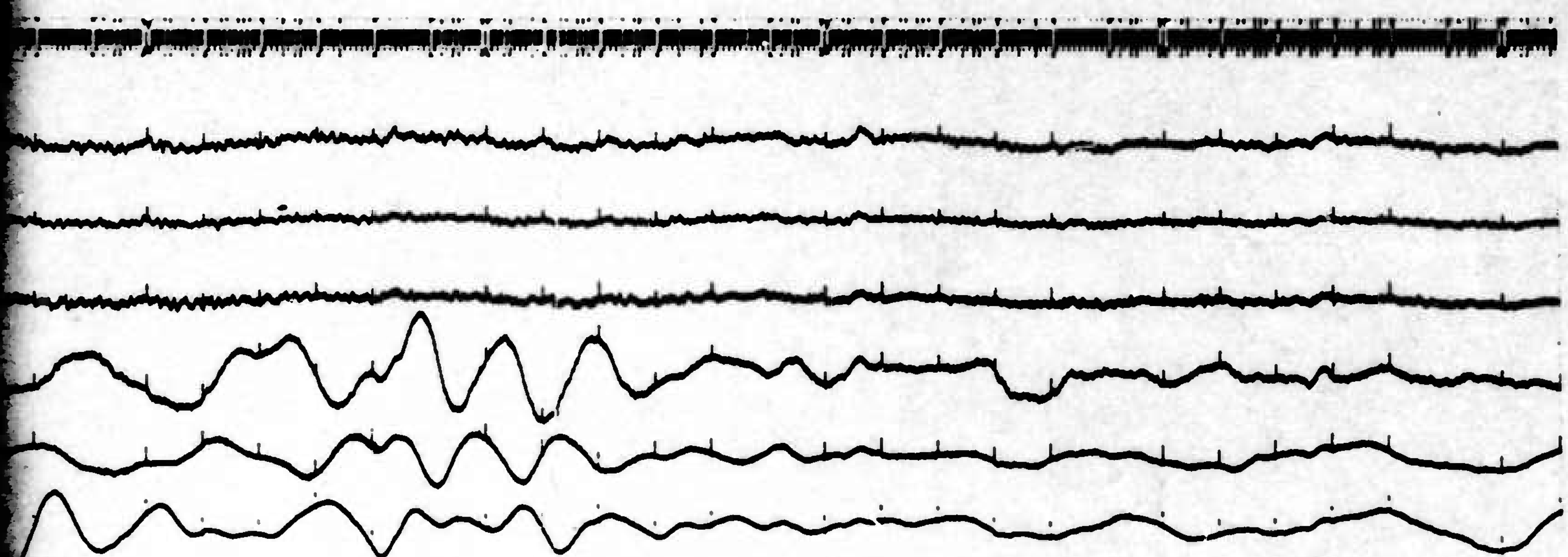


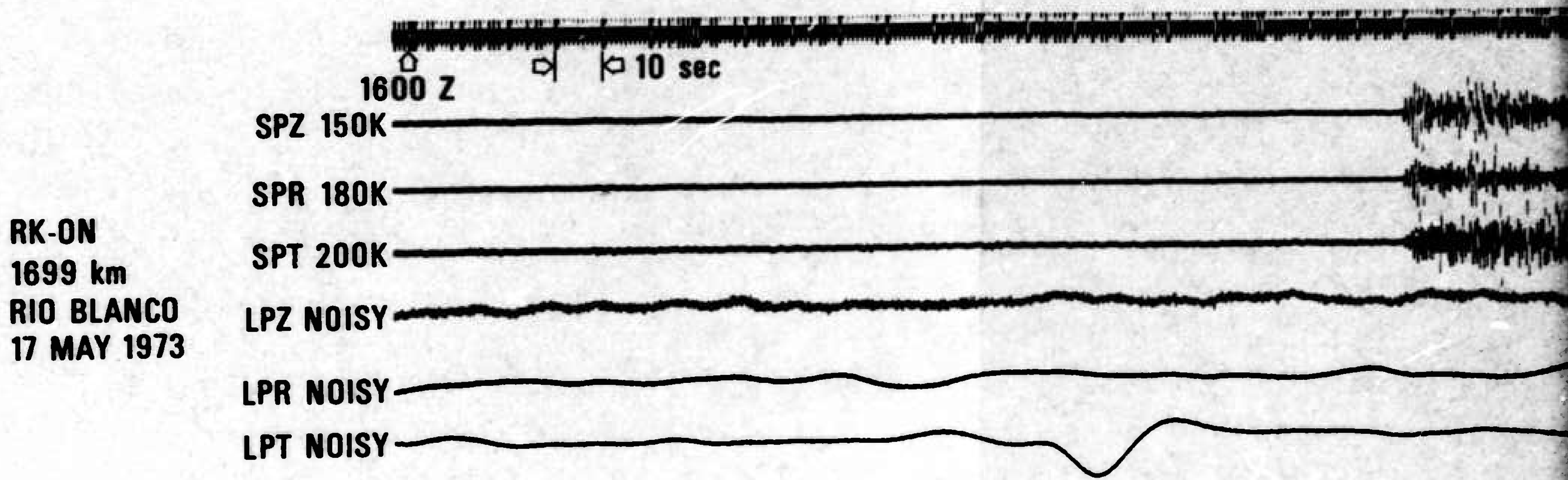

PG2BC
1942 km
RIO BLANCO
17 MAY 1973
10 sec
SPZ 123K
SPR 103K
SPT 103K
LPZ 27.9K
LPR 27.6K
LPT 27.2K

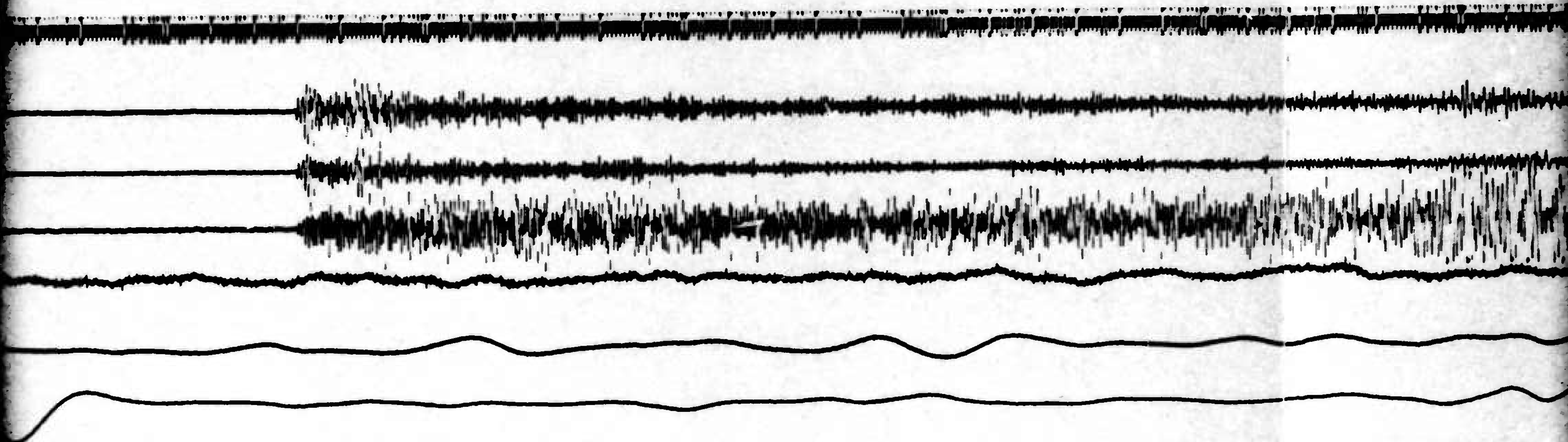

1600Z

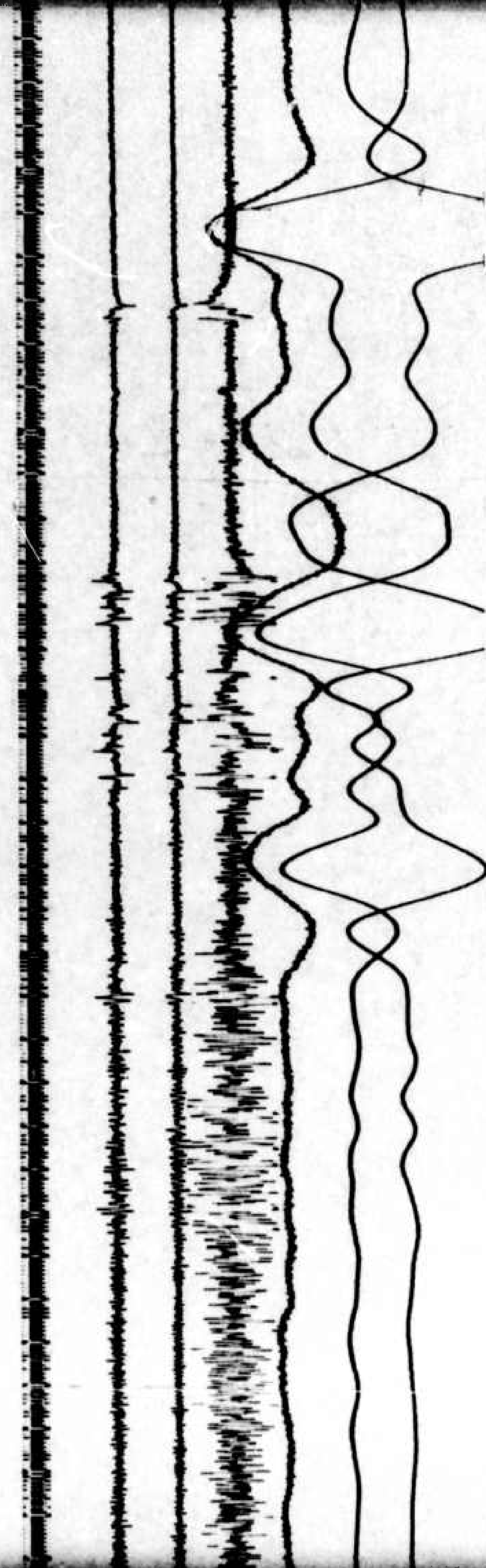


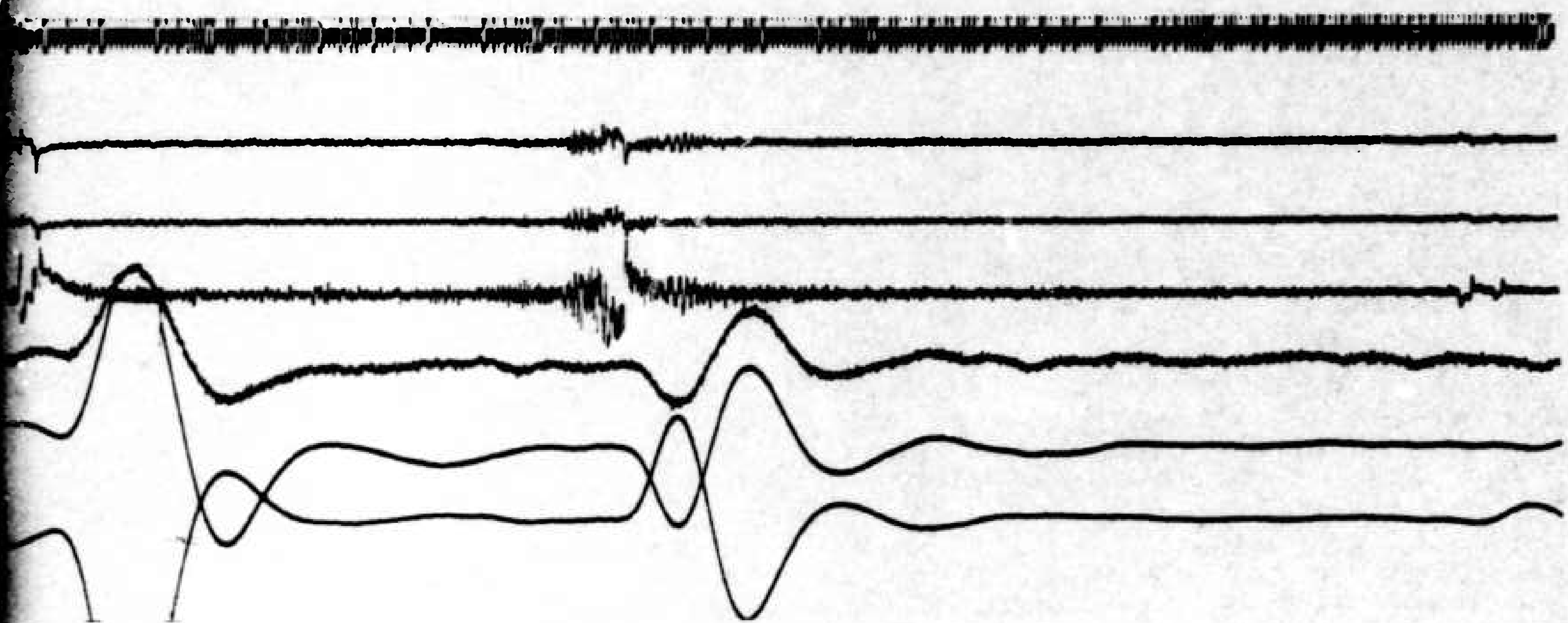


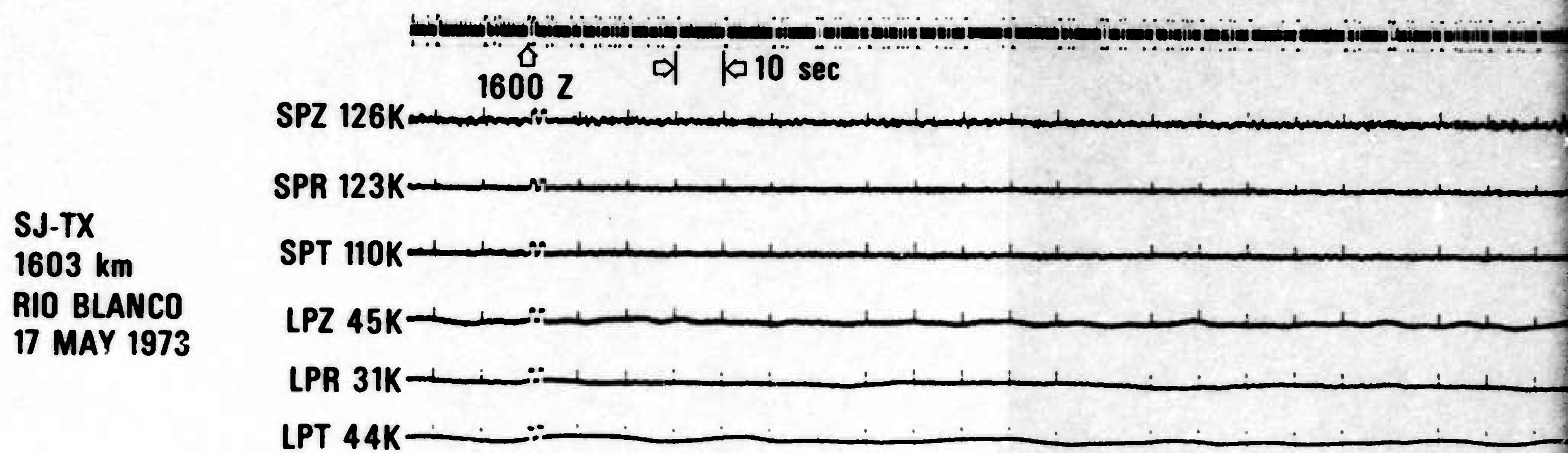


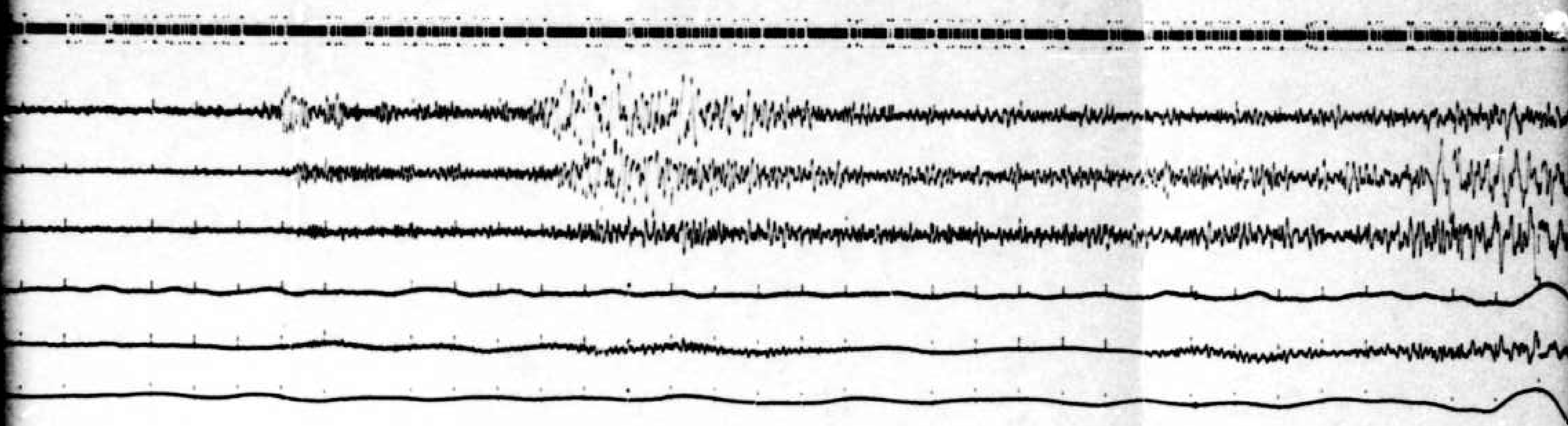

RK-ON
1699 km
RIO BLANCO
17 MAY 1973
1600 Z
10 sec
SPZ 150K
SPR 180K
SPT 200K
LPZ NOISY
LPR NOISY
LPT NOISY

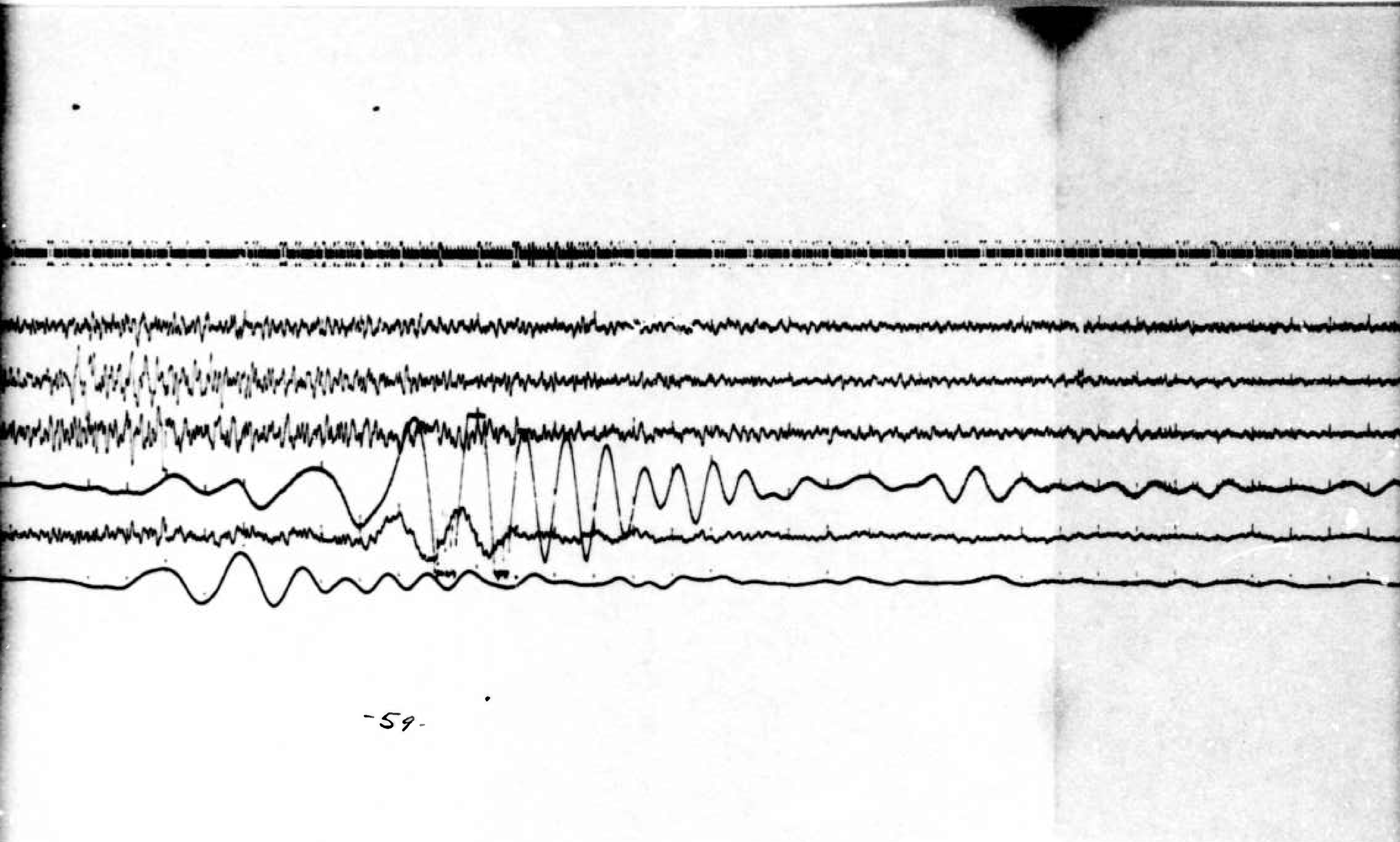


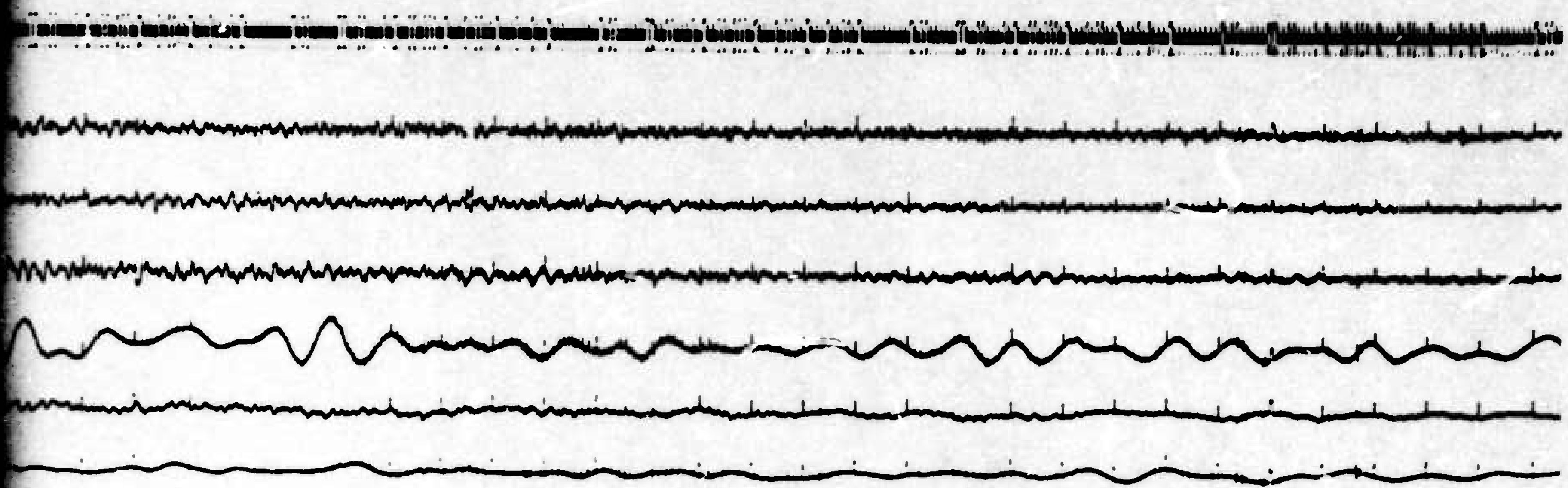


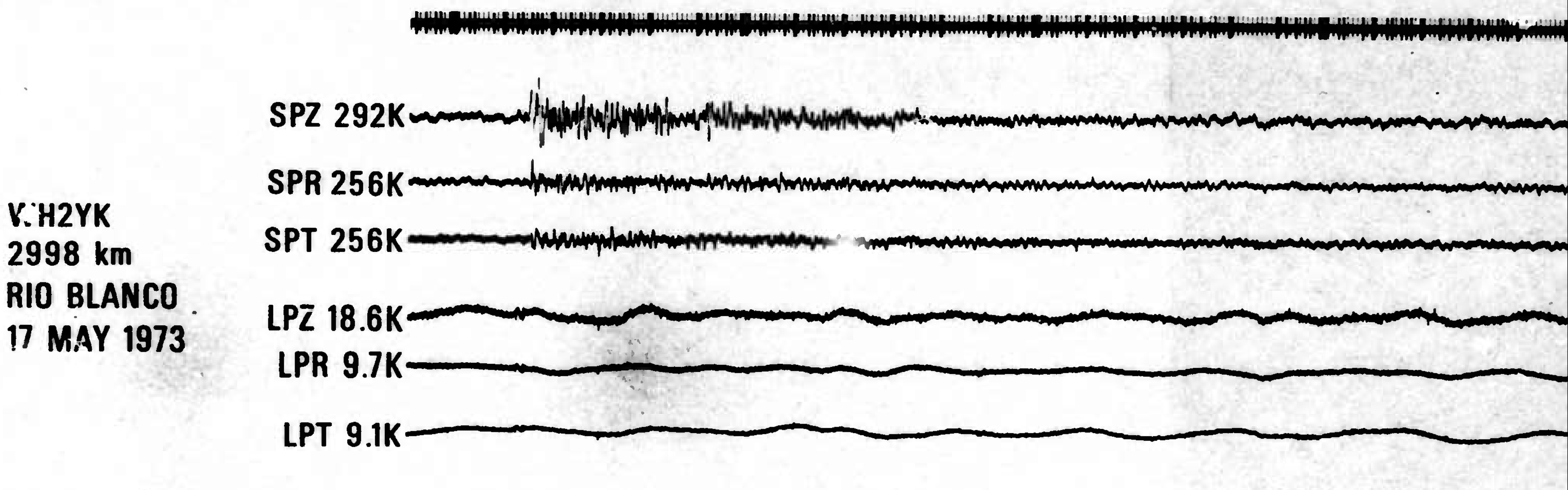


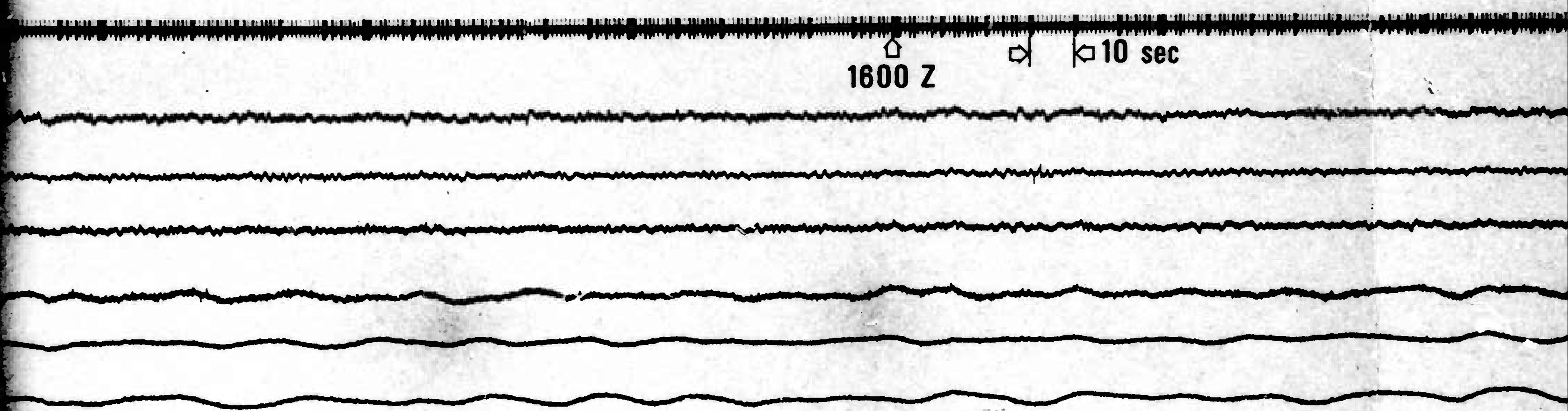

SJ-TX
1603 km
RIO BLANCO
17 MAY 1973
1600 Z
10 sec
SPZ 126K
SPR 123K
SPT 110K
LPZ 45K
LPR 31K
LPT 44K

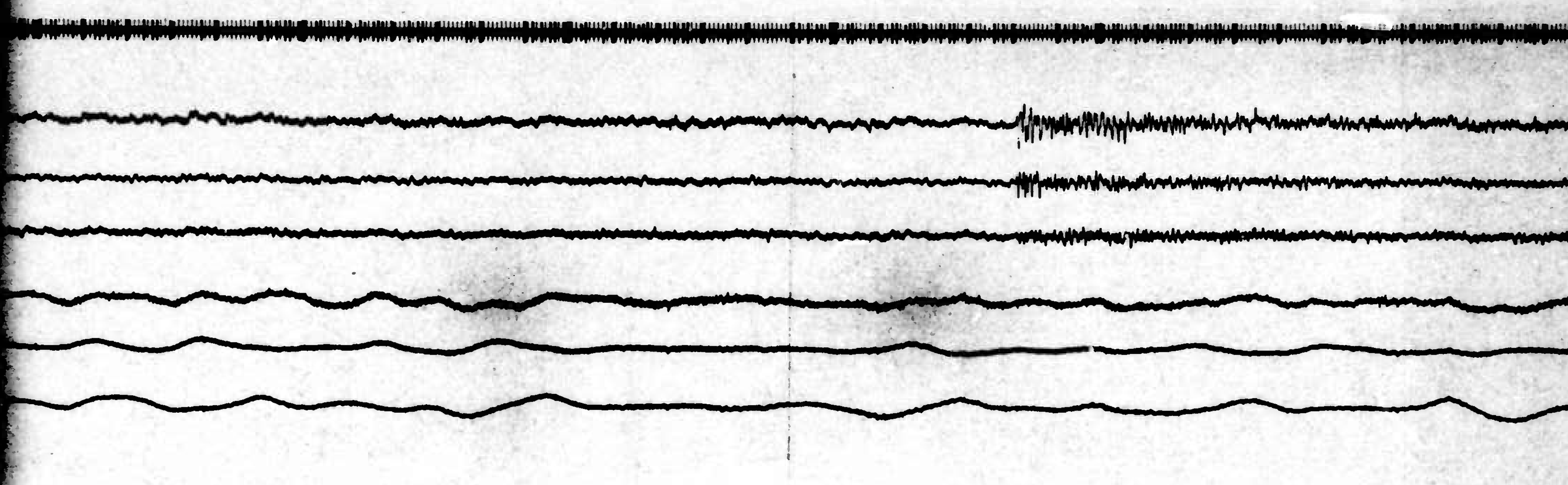


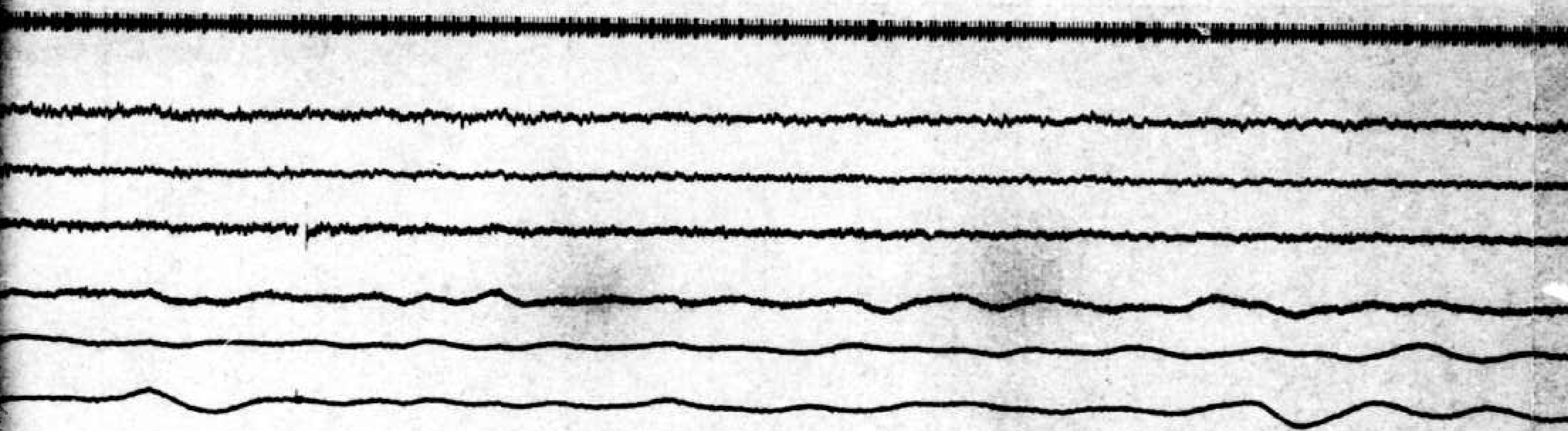


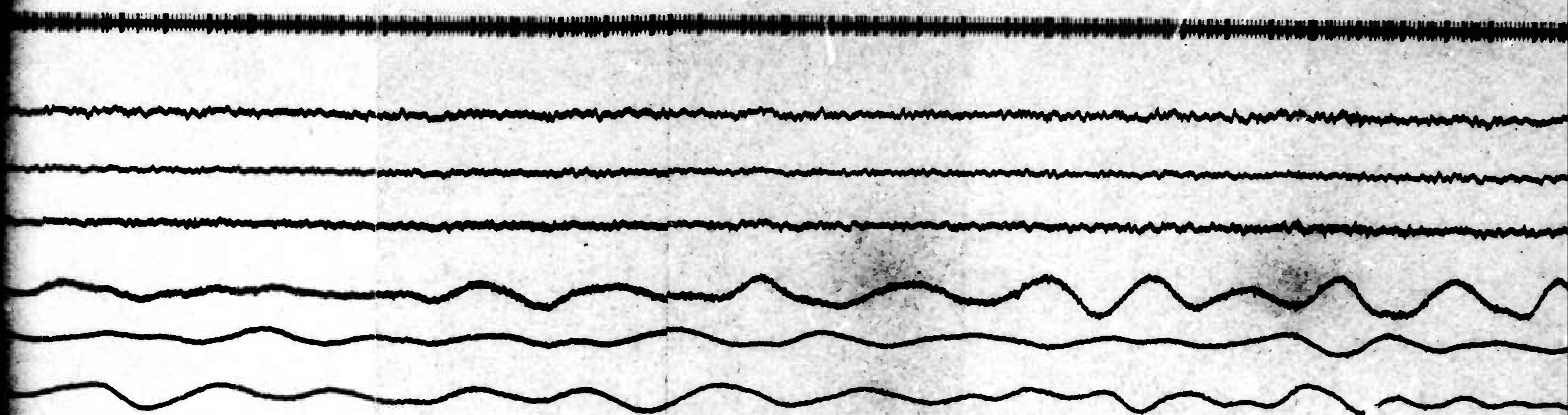


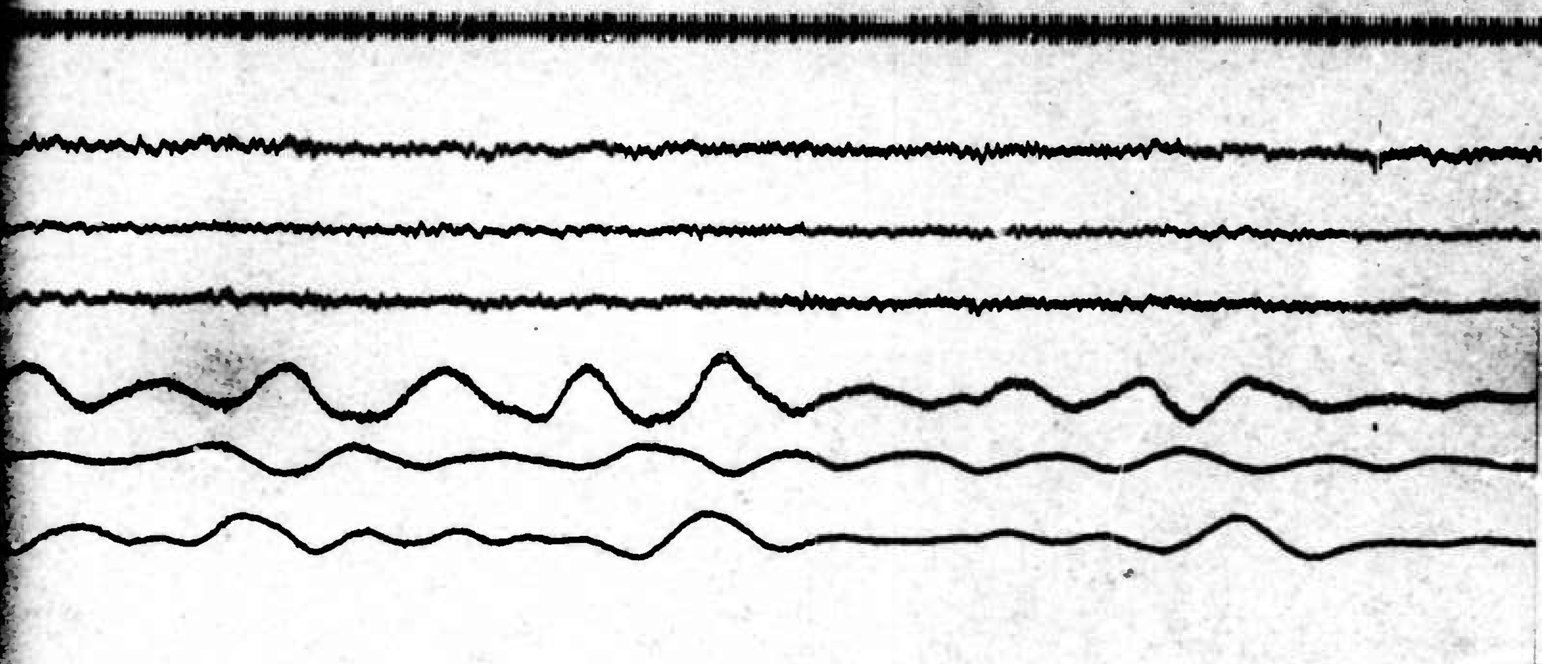

V:H2YK
2998 km
RIO BLANCO
17 MAY 1973
SPZ 292K
SPR 256K
SPT 256K
LPZ 18.6K
LPR 9.7K
LPT 9.1K


1600 Z
10 sec









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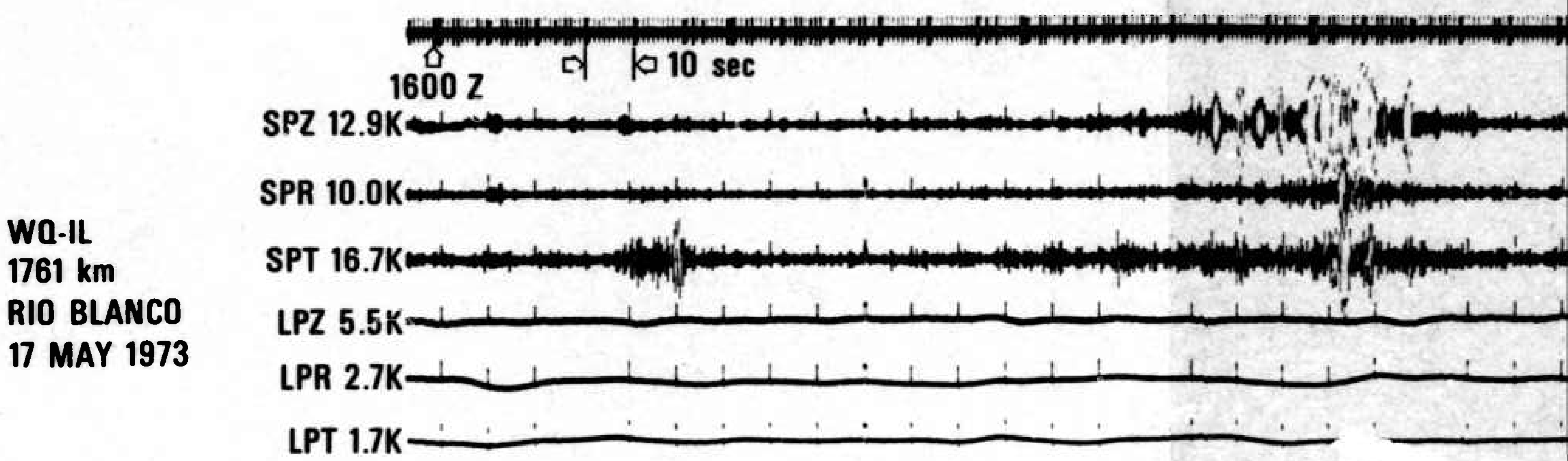
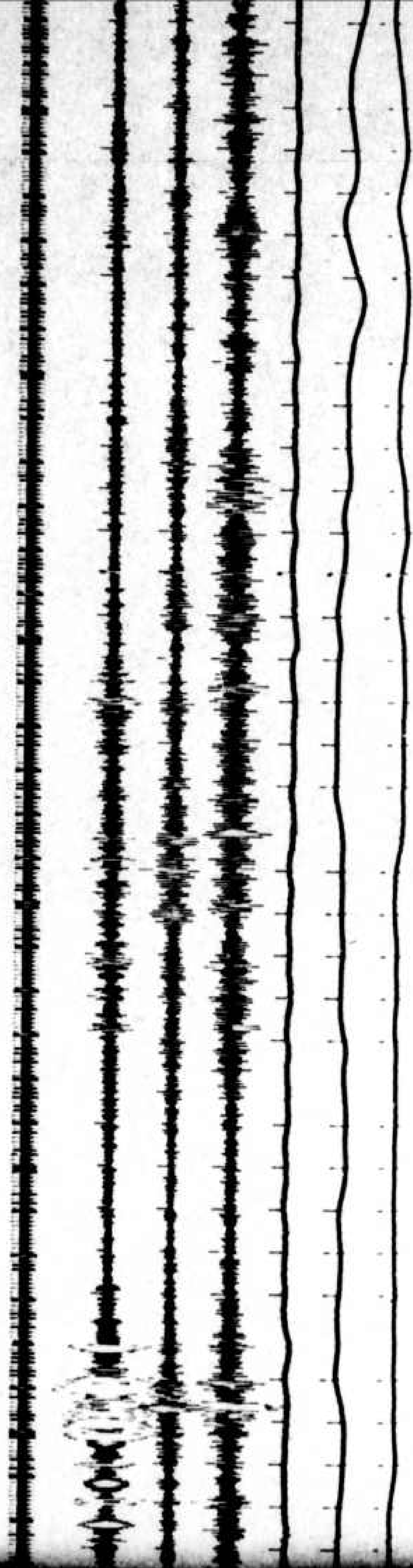
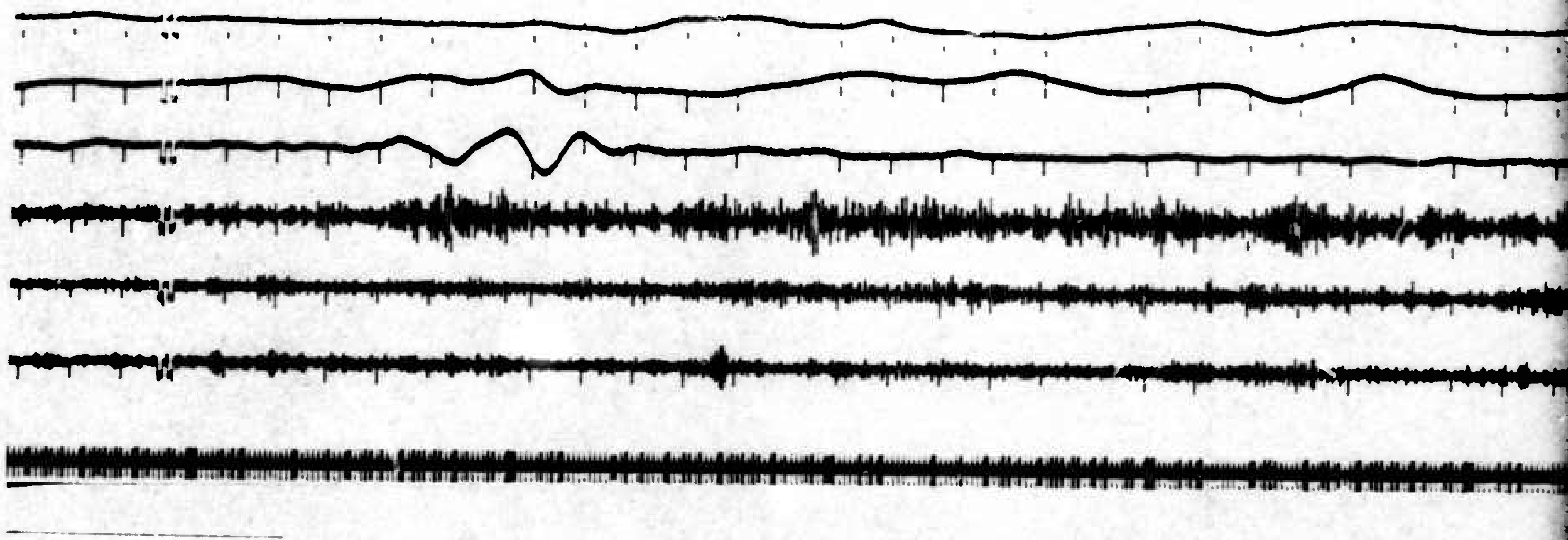

WQ-IL
1761 km
RIO BLANCO
17 MAY 1973
1600 Z
10 sec
SPZ 12.9K
SPR 10.0K
SPT 16.7K
LPZ 5.5K
LPR 2.7K
LPT 1.7K

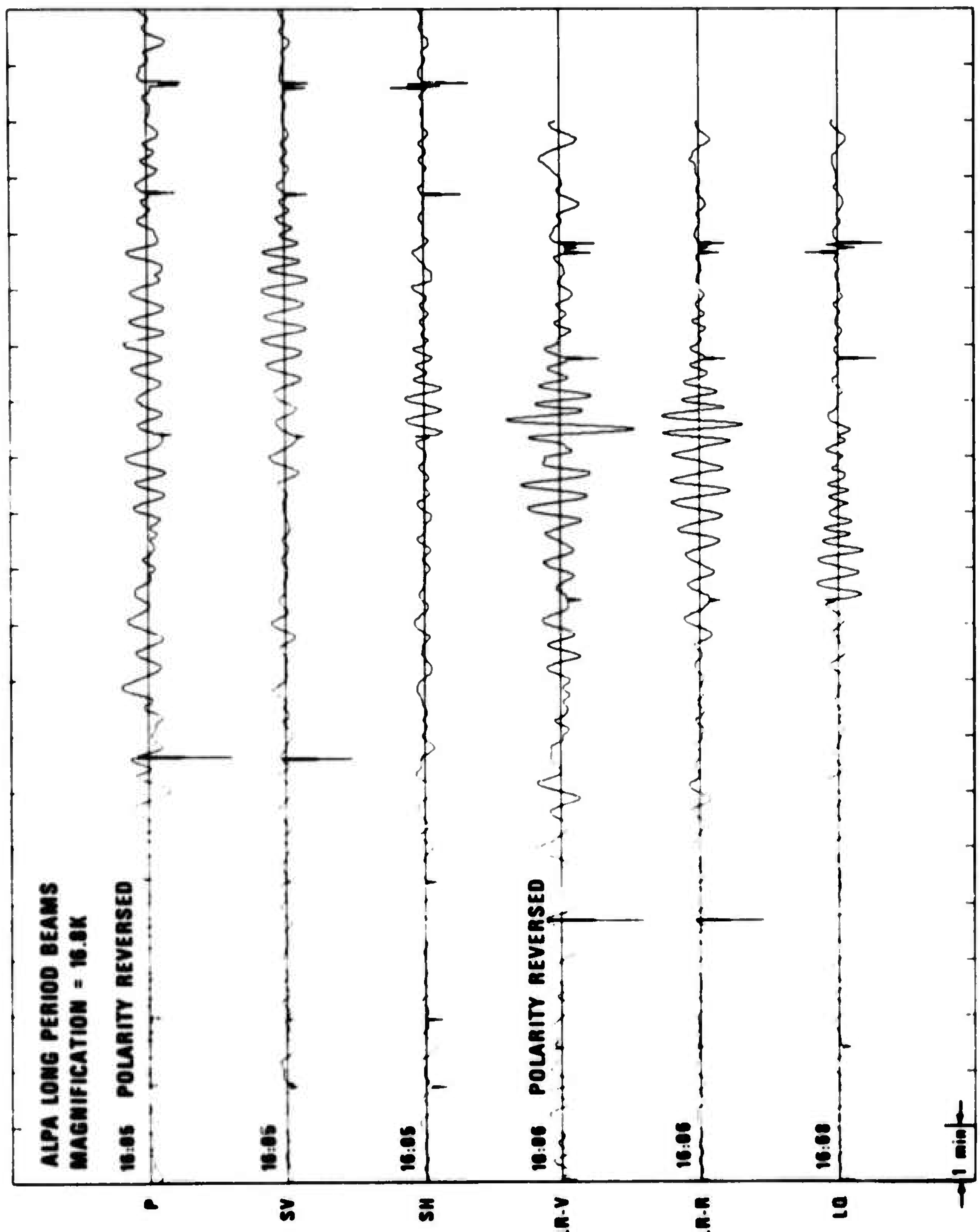
-66-



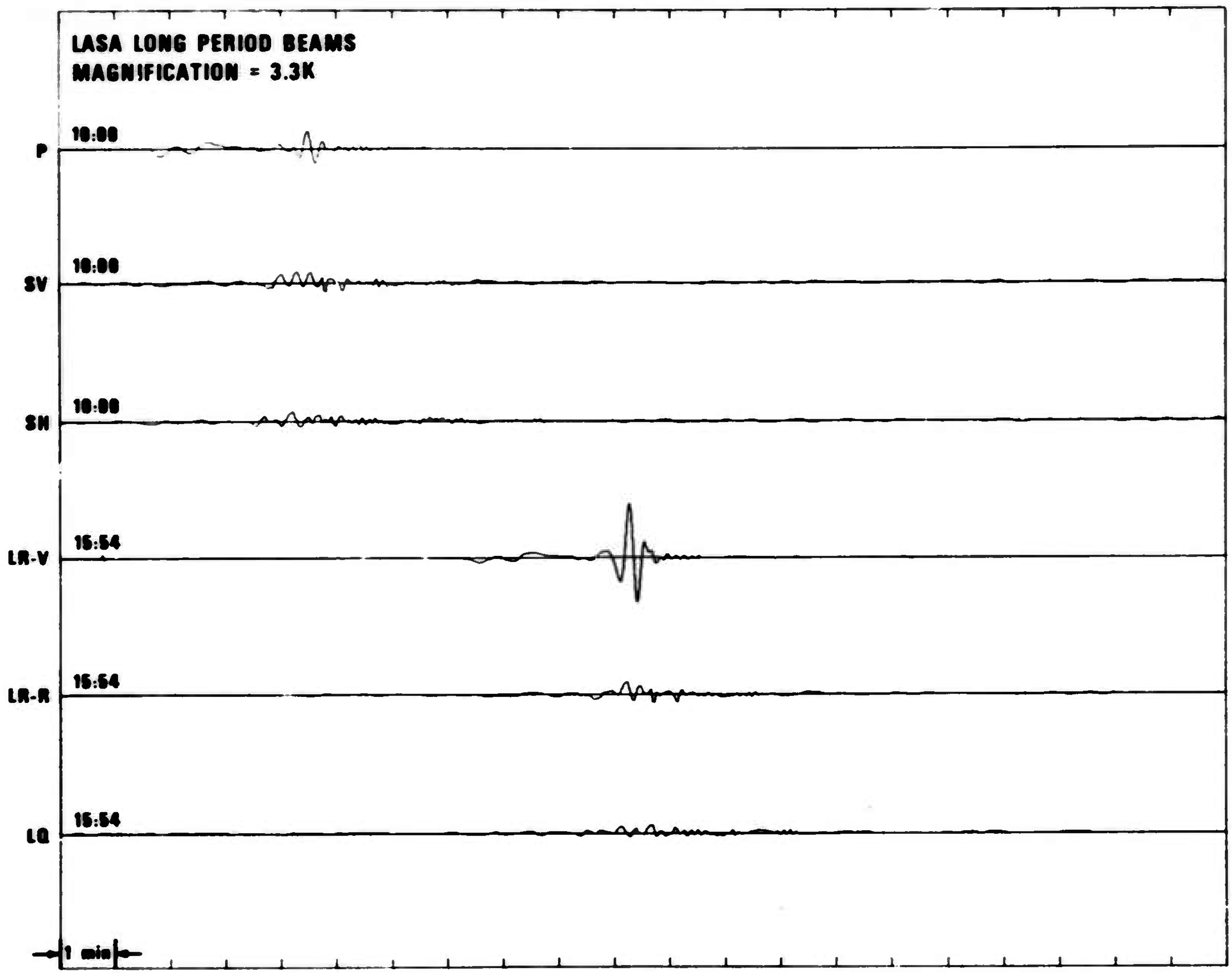


APPENDIX II

ARRAY DATA

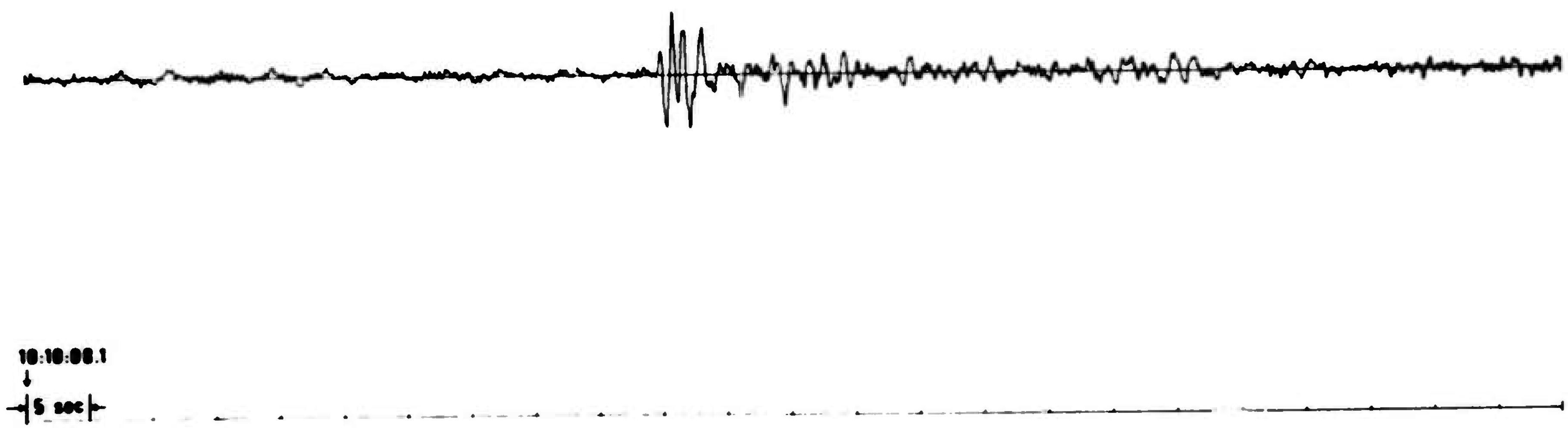


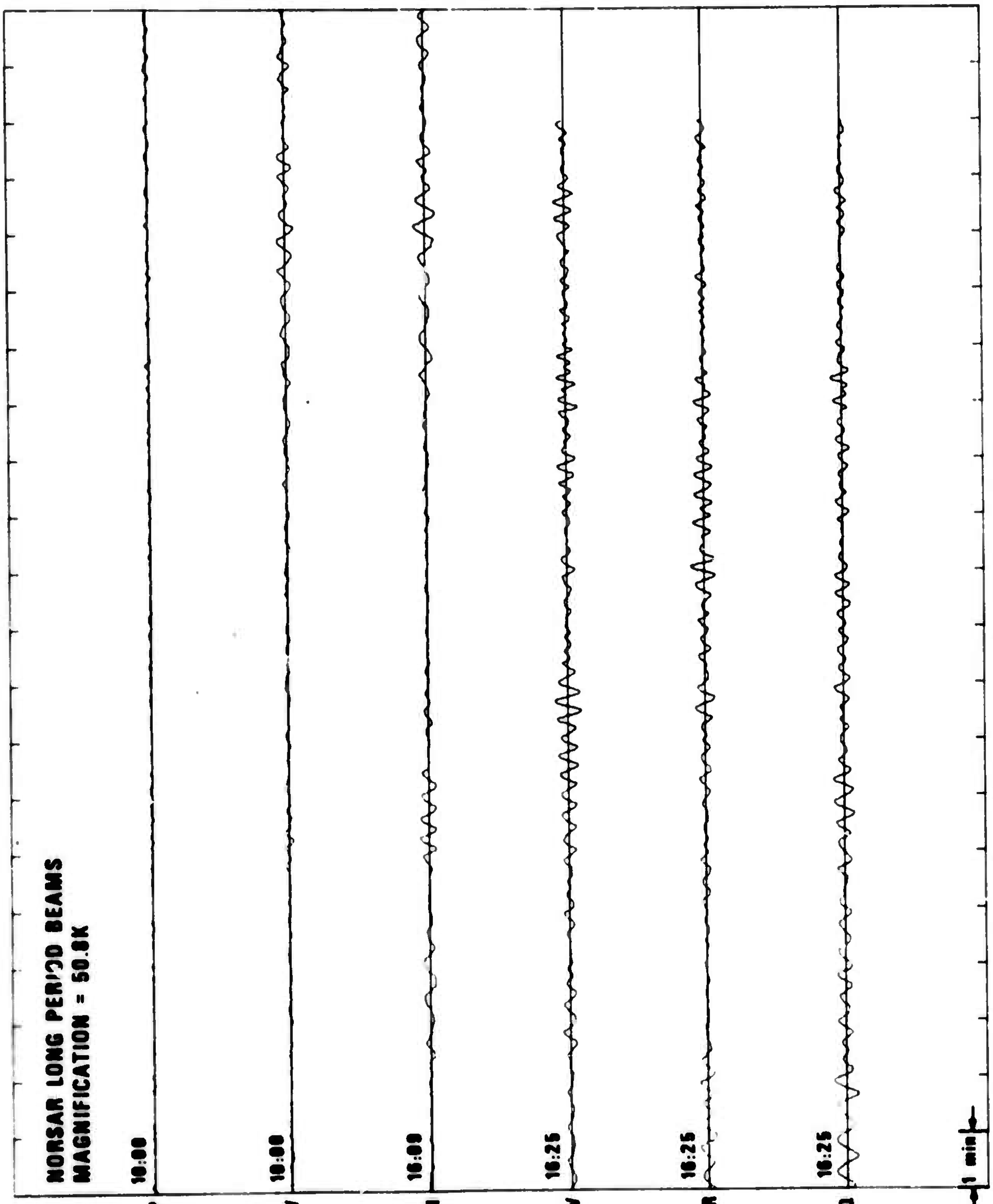
ALPA LONG PERIOD BEAMS
MAGNIFICATION = 16.8K
POLARITY REVERSED
POLARITY REVERSED
16:05
16:05
16:05
16:06
16:06
16:06
P
SV
SH
LR-V
LR-R
LQ
1 min



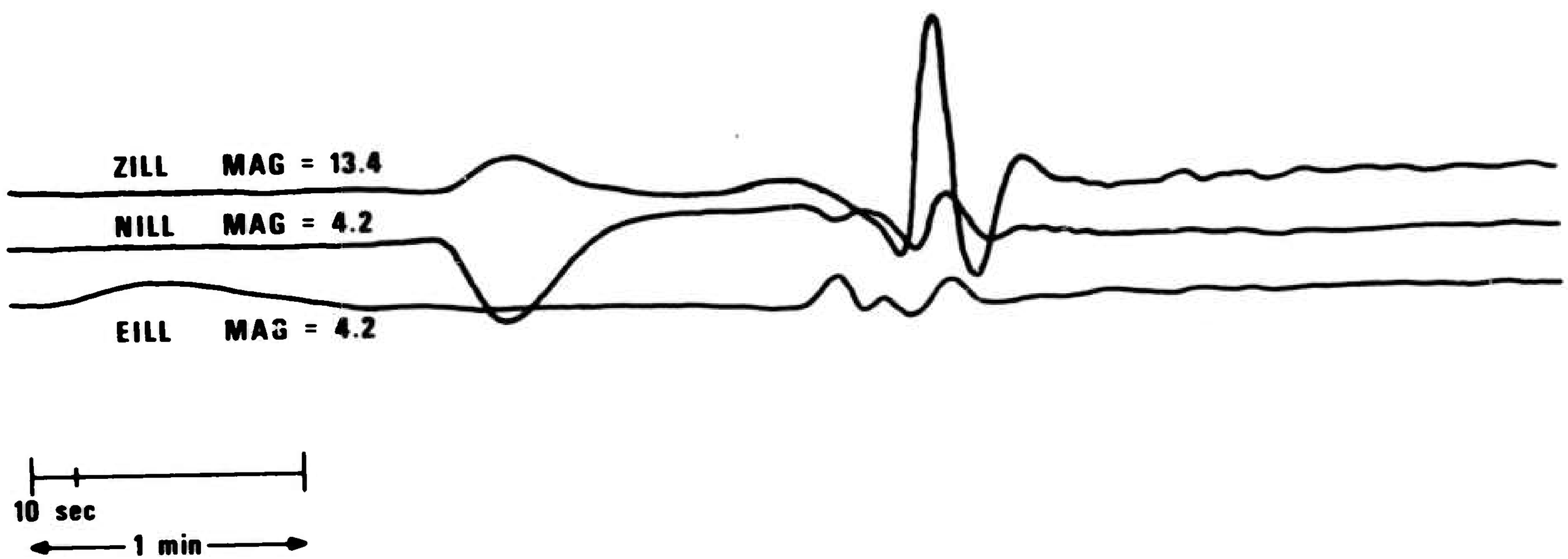
LASA LONG PERIOD BEAMS
MAGNIFICATION = 3.3K
P
10:00
SV
10:00
SH
10:00
LR-V
15:54
LR-R
15:54
LQ
15:54
1 min

KORSAR SP BEAM
MAGNIFICATION = 131K





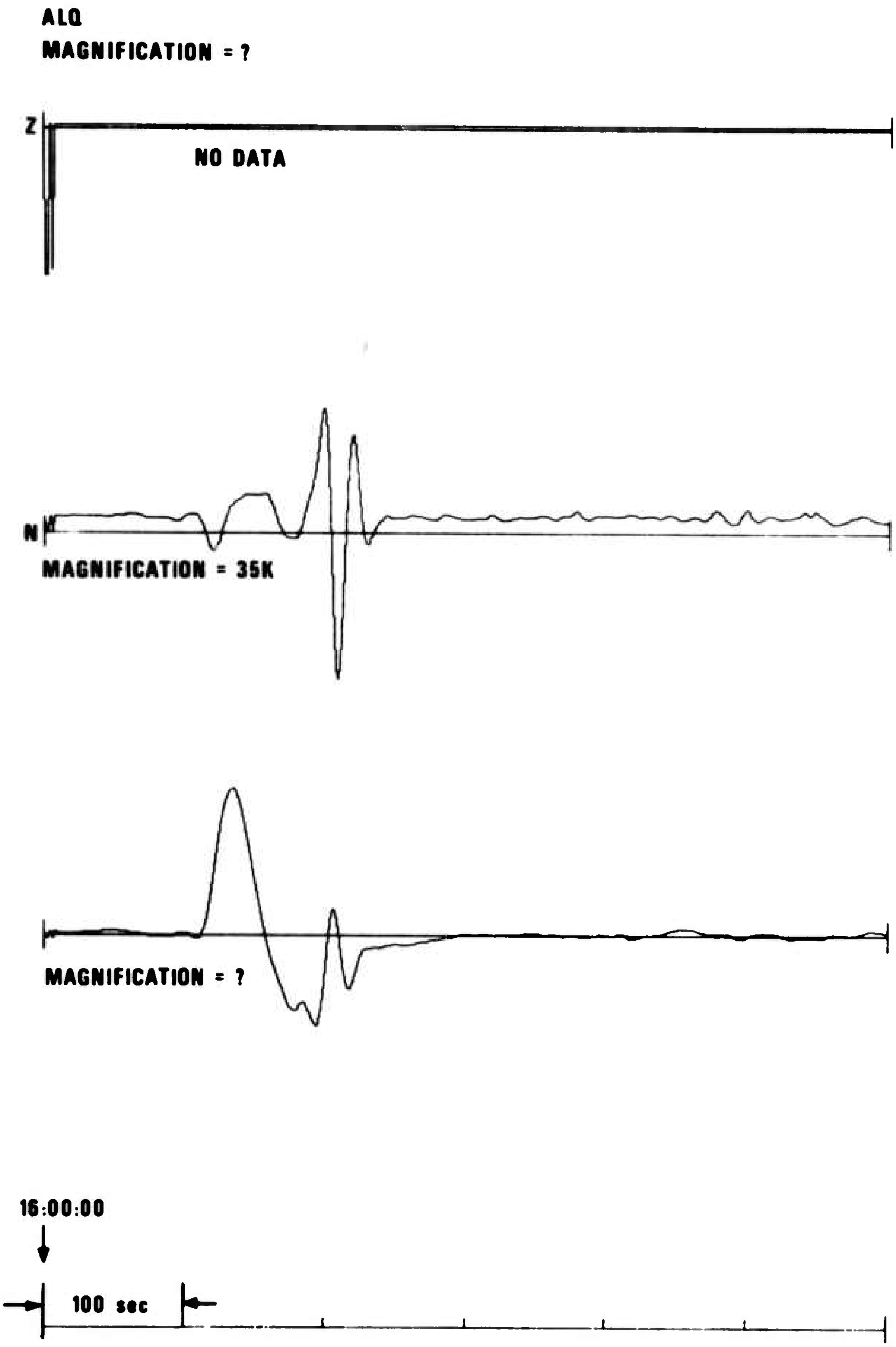
NORSAR LONG PERIOD BEAMS
MAGNIFICATION = 50.0K
16:00
16:00
16:00
16:25
16:25
16:25
P
SV
SH
LR-V
LR-R
LQ
1 min

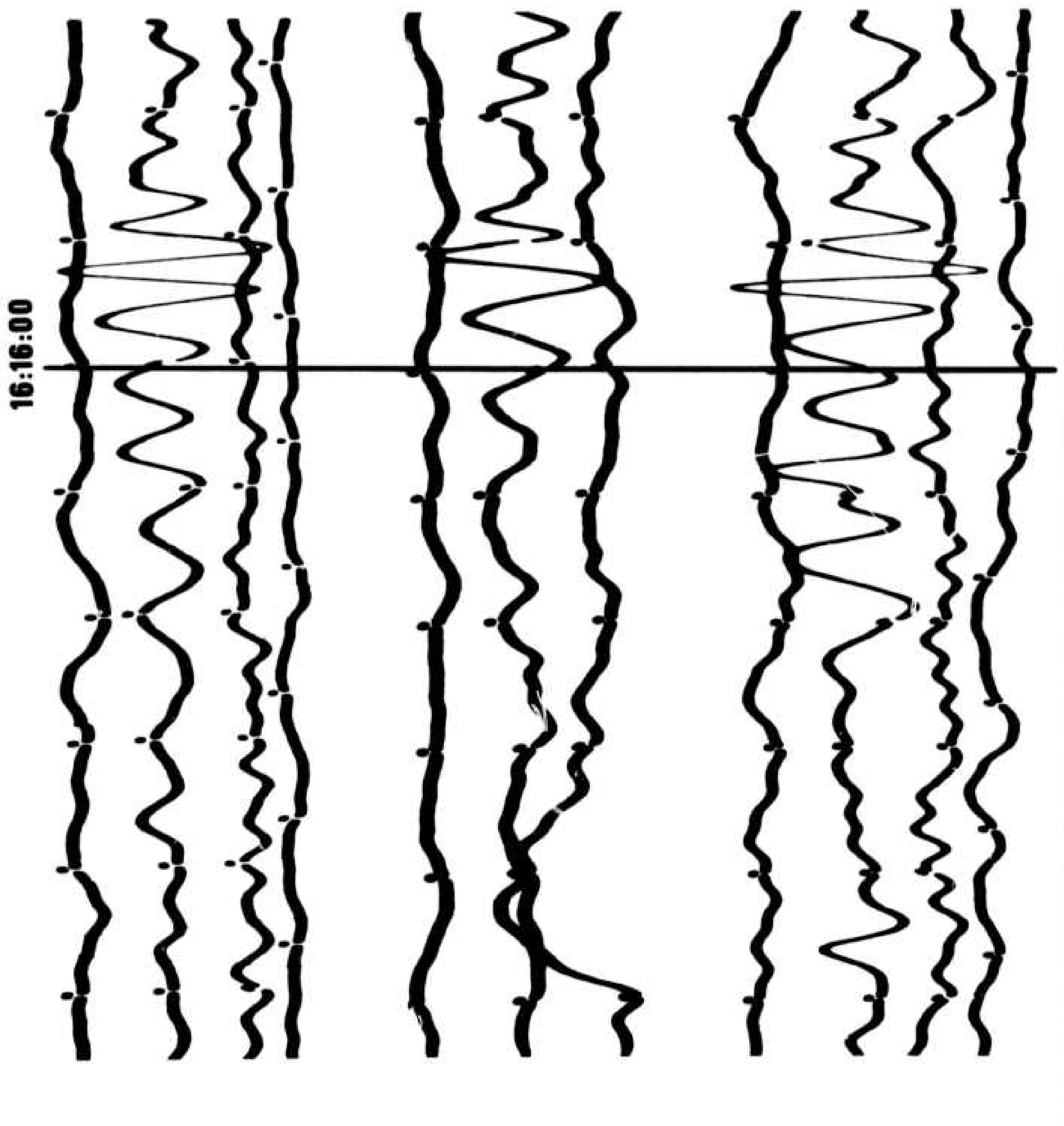


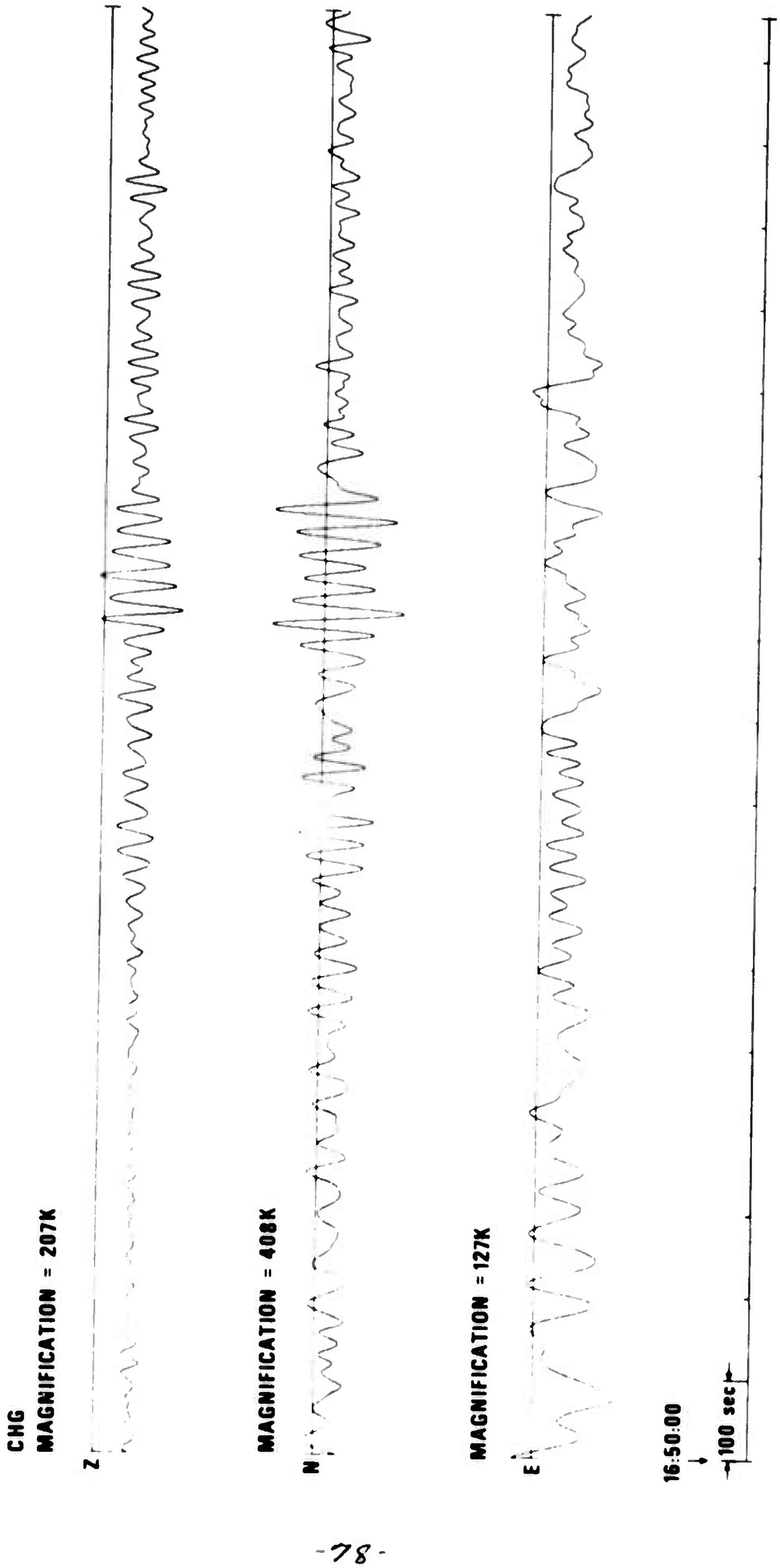
TFO

APPENDIX III

LPE DATA

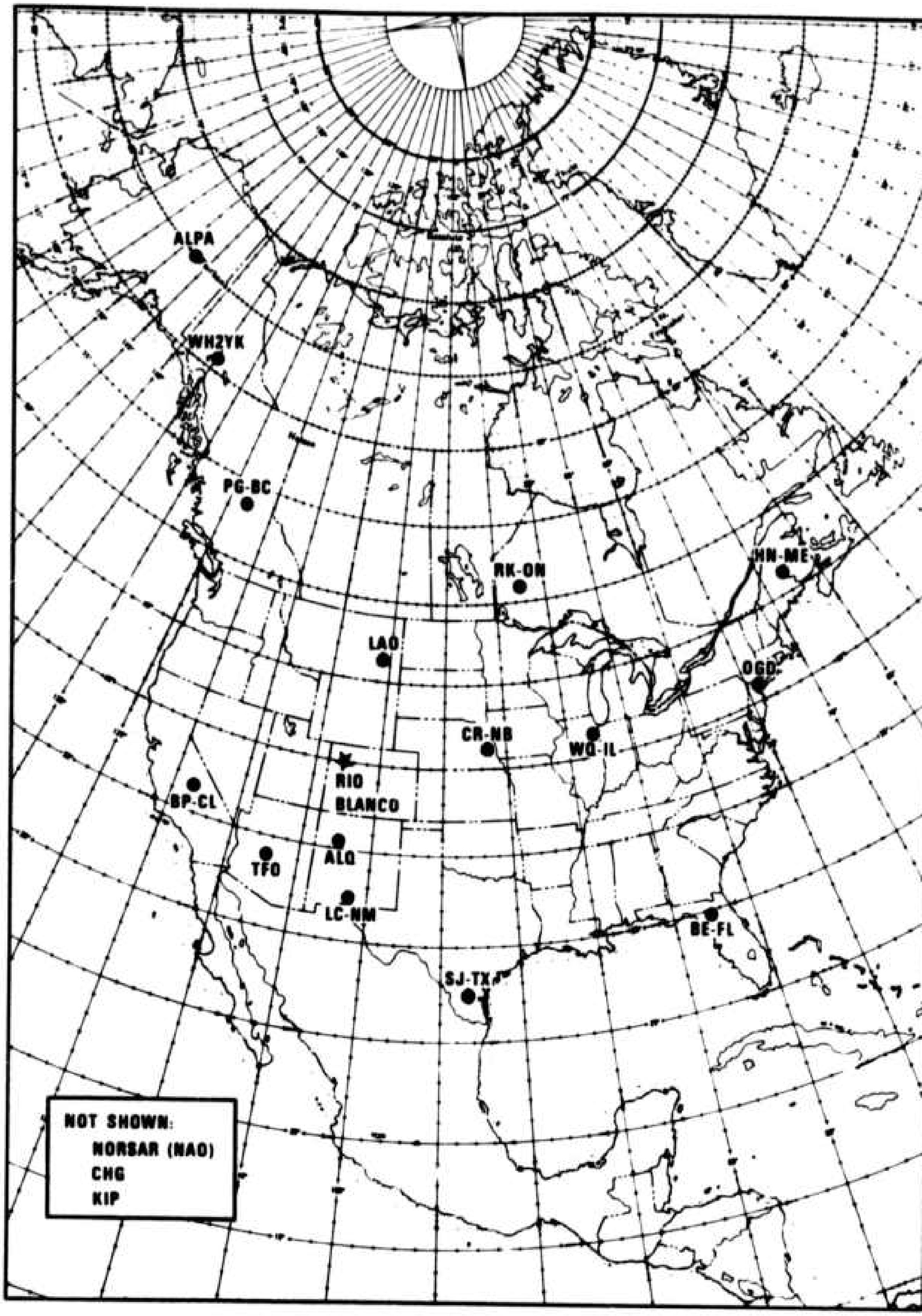

ALQ
MAGNIFICATION = ?
Z
NO DATA
N
MAGNIFICATION = 35K
MAGNIFICATION = ?
16:00:00
100 sec


16:16:00
OGD
Z
70K
N
94K
E
159K


CHG
MAGNIFICATION = 207K
Z
MAGNIFICATION = 408K
N
MAGNIFICATION = 127K
E
16:50:00
100 sec

APPENDIX IV

STATION MAP


ALPA
WH2YK
PG-BC
RK-ON
HN-ME
LAO
OGD
CR-NB
WO-IL
RIO
BLANCO
BP-CL
ALQ
TFO
LC-NM
BE-FL
SJ-TX
NOT SHOWN:
NORSAR (NAO)
CHG
KIP